

Design and Construction of a Tachometer



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Project Outline

In this project the student will design and construct a contact-less tachometer which could be used in the power engineering lab. The output should be a 6-digit display of revs/min and radians per second. The device should enable the use of several sensors (such as optical or Hall Effect). The device should be tested to demonstrate the ability to display at least 5 significant figures after a reasonable gating period.

I Acknowledgements

I'd like to say thank you to Dr Gareth Lee for being my supervisor and coach throughout this thesis and Dr Sujeewa Hettiwatte for providing project specifications.

I'd like to thank Mr lafeta Laava for helping me build my circuit and attaching wires with headers very neatly which made my circuit look professional.

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I'd like to thank "that computer shop" for recovering part of my thesis after I incurred a corrupt hard drive. Note to self and others: back up your work!

And finally I'd like to thank all the websites online who have relinquished their copyright so it can be used in this thesis to explain topics in more clarity.

II Abstract

The purpose of this report is to provide a guided tour of how everything was achieved by choosing the right parts, implementation and building, testing, results and of course to inspire future projects and students into making student level tachometers because they all come in different shapes and sizes. A microcontroller programmed using the Arduino software on Microsoft Windows in a combination of C and C++ was used to control various circuitry and brought the device to life with the Arduino software and a few external libraries. Various alterations and upgrades could be made to this device as this thesis only explores a fraction of the endless possibility of technologies, methods, programs, and electrical components.

This thesis paper contains extensive research and will explore where tachometers came from and the current sensor technology used today such as the Hall Effect, generator, light reflected from a laser or an optical encoder that can determine position of a rotating device. The different technologies' advantages and disadvantages will be looked into because in differing circumstances one might be better than the other. The specifications for this thesis are to measure and display the movement of a rotating machine in revolutions per minute or radians per second. The idea of the project was to make all the parts fit into a box and make it portable so getting the right battery was a cost versus function compromise.

Tachometers are essentially used for measuring speed and can be in turn, control manually or automatically some aspect of the measured machine. Tachometers can be used for scheduling maintenance after certain mileage and therefore reducing costs over a machine's lifetime.

The basis for measurement is by using the Arduino's interrupt function which will take quick and accurate time based measurements. The internal pull up resistor built into the Arduino's board will ensure no false positives are recorded when a falling edge is present on the interrupt pin. Specifications from data sheets are examined in great detail to prevent damage to any of the components and part of the method is testing along the way and looking for problems and solutions.

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VI List of Terms and Abbreviations

Analogue	- A value that can take a range of values rather than only on or off
Ambient	- Surrounding environment
Binary	- Base 2, expressed as 1 or 0
Bug	- Glitch in soft or hardware
Centrifugal force	- An outward body rotating about an axis creating a force
Controller	- Something that regulates
Current	- Flow of electrons
DC	- Direct current
Debugging	- Act of removing glitches from software or hardware
Deep cycle	- The ability to discharge most of a batteries capacity
Dendrites	- Branching figure or marking (mineralogy)
Digital	- Readable and manipuable by a computer
Electrochemical	- Chemical changes that produce electricity
Electrodes	- A conductor not necessarily metallic
Flux	- Magnetic strength
Hall effect	- Effect on electrons in a plate with a magnetic field present
IDE	- Integrated development environment
IEEE	- Institute of Electrical and Electronics Engineers
ISR	- Interrupt service routine
Keypad	- A panel of numerical keys for use in calculators for example
Laser	- Lightwave Amplification by Stimulated Emission or Radiation
LCD	- Liquid crystal display
LED	- Light emitting diode
Ohms	- Unit for measuring electrical resistance
Polymer	- A compound of high molecular weight
RPM	- Revolutions per minute
RADs	- Radians per second
Sensor	- A device to sense light, temperature etc.
Syntax	- Grammatical rules and structural patterns in computers
Tachometer	- A speed measuring device
Voltage	- Electrical potential
Parallel/Series	- Modes of communication singular or many at once
Zener diodes	- A diode that allows a reverse voltage to remain almost constant across it

1 Background

A tachometer is a device used to measure rotational speed of a machine. This device usually displays the rotational speed in revolutions per minute (RPM) on a digital display, traditionally on an analogue display. The word tachometer comes from Greek *Tαχος*, *tachos*, which means speed and *metron* which means to measure. The first documented use of a tachometer was by an engineer named Dietrich Uhlhorn in 1817, who is the assumed inventor. No one is sure of who invented the first tachometer [1] but it was based on measuring the centrifugal force, comparable to the centrifugal governor shown in figure 1. Figure 1 shows a self-regulating device for controlling the flow rate of a liquid. The first tachometer used the centrifugal force of the balls which moved outwards as they rotated (driven by steam in a pipe) and was attached to an indicator or needle that showed the speed. Later it was used to measure the speed of locomotives in 1840. [2]

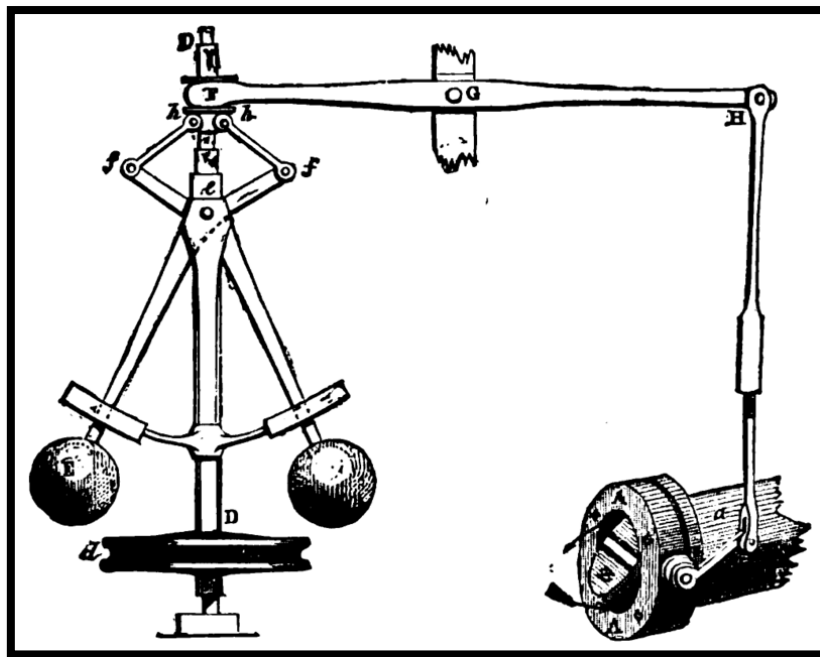


Figure 1 - Centrifugal Governor [3]

2 Introduction

Tachometers are needed in modern times to measure the rotational speed of numerous things. It is advantageous to know the duration of time and the speed of a moving object then the distance can be calculated and maintenance can be scheduled to prevent wear and tear. The most common tachometers are used in vehicles to determine speed and distance. There are many ways to measure rotational speed and this thesis will present the method used to make a tachometer and some problem encountered while building one. The speed of detection of the movement will be considered when building a tachometer.

3 Initial Steps

To design anything it requires extensive planning. This planning should be kept simple and open-ended for any additions to the project or unseen problems that may arise. There needs to be a clear goal so that it can be broken up into smaller parts as stepping stones for the final outcome. Once those stepping stones are absolutely crystal-clear then focus and resources can be applied to reaching the desired result.

3.1 Brain Storming and Research

First and foremost the question of "what is a tachometer?" has to be answered. How does it work? What can this project achieve? Ideas and creative notes are taken down for later utilization. Seemingly endless models exist on the market with functions that can be duplicated in this project, along with things that can be added for a unique touch. The standard amongst the tachometers, after some quick searching, that can be bought is that they all have a display. This LCD display will indicate RPM and/or RAD/s and/or a counter to show how many times the revolving object has spun in a fixed period of time. Some of the tachometers will include a combination of either or both contact and non-contact measurements.

3.2 Modern Technologies

There are many ways to calculate the speed. Some technologies include, like this first tachometer, the measurement of centrifugal force. Some of the modern tachometers will use light such as a laser and a sensor, similarly an optical encoder, some tachometers will use contact and induce a spin on an internal motor for measurement, once fitted with a magnet the speed can be measured using the Hall effect, and there are other numerous way to measure such as connecting a measuring device directly to the spark plugs of a car to measure the piston motion's RPM.

Generator

It is common knowledge that when a voltage is applied across a motor's terminals current will flow and the motor will spin. Various different motors will produce different results and to demonstrate a voltage versus speed graph is shown in figure 2. By the graph's information it is concluded that the more that voltage is applied the faster a motor will spin.

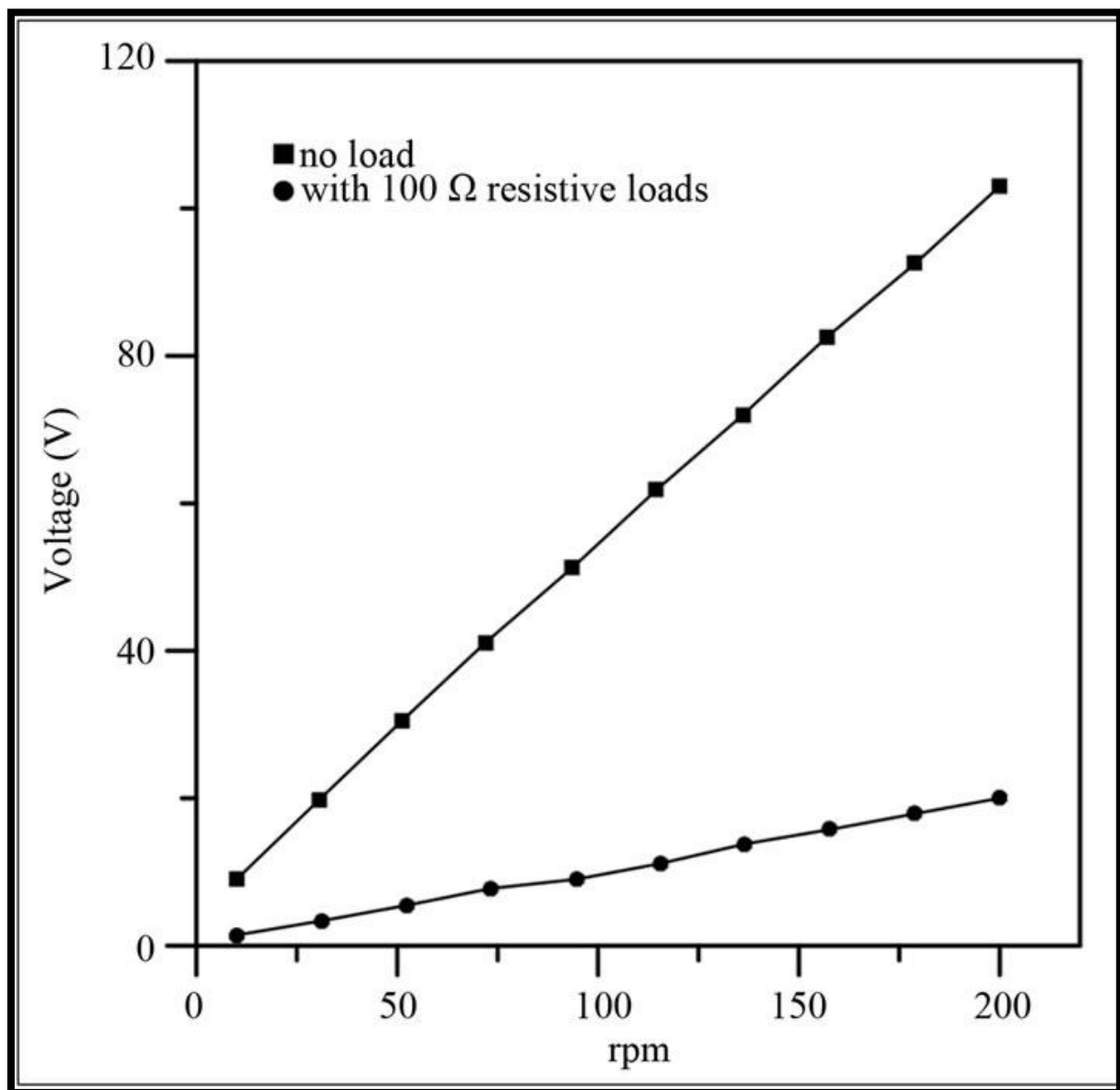


Figure 2 - Voltage vs. RPM plot [4]

To make a voltage generator the opposite is true: when a force is applied to a motor it will generate a voltage across its terminals. This is called Faraday's law. When there is a coil around a changing magnetic field, the coil will produce a current in the coil, which is called electromagnetic induction there are many ways to produce this effect. Voltage can be generated by changing the flux inside a wound coil, by moving a magnet towards a coil, changing a magnetic field, or rotating a coil inside a

magnetic field. [5] An example of a tachometer that uses voltage generation is shown below in figure 3 with the contact part towards the top.



Figure 3 - Contact generator tachometer [6]

While this method is very easy to use and will almost always produce results there are a few disadvantages. One of the disadvantages is that the output of the generator (DC or AC) is that when using a simple motor, at some point the coil will be parallel to the magnet which will not produce a voltage shown in figure 4. This can be fixed with a capacitor to try and level off the voltage to make it seem like a DC voltage, unfortunately at low speeds this is not effective due to the capacitor rapidly losing charge. There is a lot of error associated with this type of measurement because unless it's well calibrated or the exact electrical motor equation is known with the constants (magnetic field strength etc.) then accurate results are not possible. Another disadvantage is that these motors or generators will have greater wear and tear on the parts compared to other technologies because of either the physical touching parts or the greater voltages and currents induced in the generator. There are also safety concerns when dealing with very large machines and can be dangerous to take a contact reading.

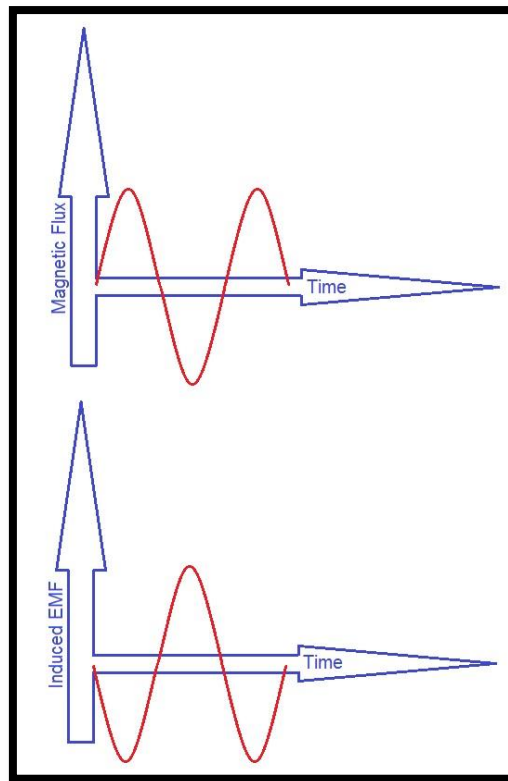


Figure 4 - Juxtaposed EMF and magnetic flux over time [7]

Hall Effect

The Hall Effect was discovered by Edwin Hall in 1879 and it was a tiny effect produced by the apparatus he was using, and it was 18 years before the electron was discovered. The Hall Effect sensor works by passing a current through a dielectric plate and in the presence of a magnetic field will produce a Hall Effect voltage. Electrons will flow from one side of the plate to the other when there is a voltage potential across it. In the presence of a magnetic field these electrons will be diverted to one side of the plate perpendicular to their original flow [8]. Shown in figure 5 is the flow of electrons shown as the thick blue arrow normally flowing to the left, the smaller arrows coming out of the plate is the magnetic field and the force is towards the page. Explained again with the right hand rule in figure 6 if the read of this thesis holds their hand with their right palm towards the paper, the fingers are straight and the thumb is perpendicular to the fingers: the fingers are the magnetic field, the thumb is the current and out of the palm is the force then this describes what is happening to the electrons that are flowing in the plate. As the electrons flow to one side of the plate and the electron holes [9] flow to the other side thus creating a voltage potential from one side of the plate to the other and this can be measure as the Hall voltage. The hall voltage is only induced when a magnetic field is present and if for example a magnet was attached to a motor then its spin could be calculated as speed with the peaks of the Hall voltage [10]. A simple circuit of the Hall Effect is shown in figure 7. Similarly to the generator method a Hall Effect probe is needed in close proximity to the machine and if it is dangerous then this is a disadvantage. Unlike the generator the voltage spike that is produced is strong (when using certain methods explained later in the thesis) and constants are not needed because the magnetic field will either be there or not.

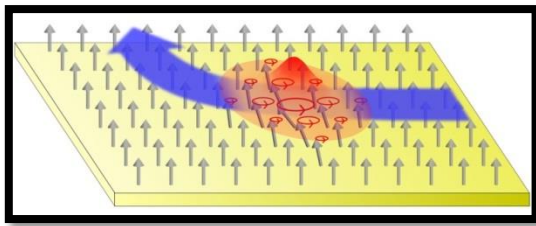


Figure 5 - Force exerted on moving electron through a magnetic field [12]

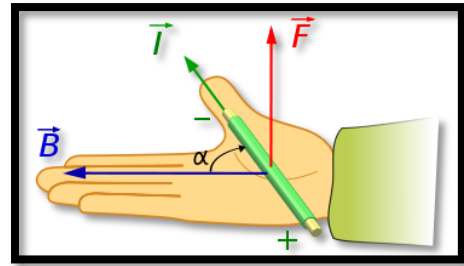


Figure 6 - Right hand rule [11]

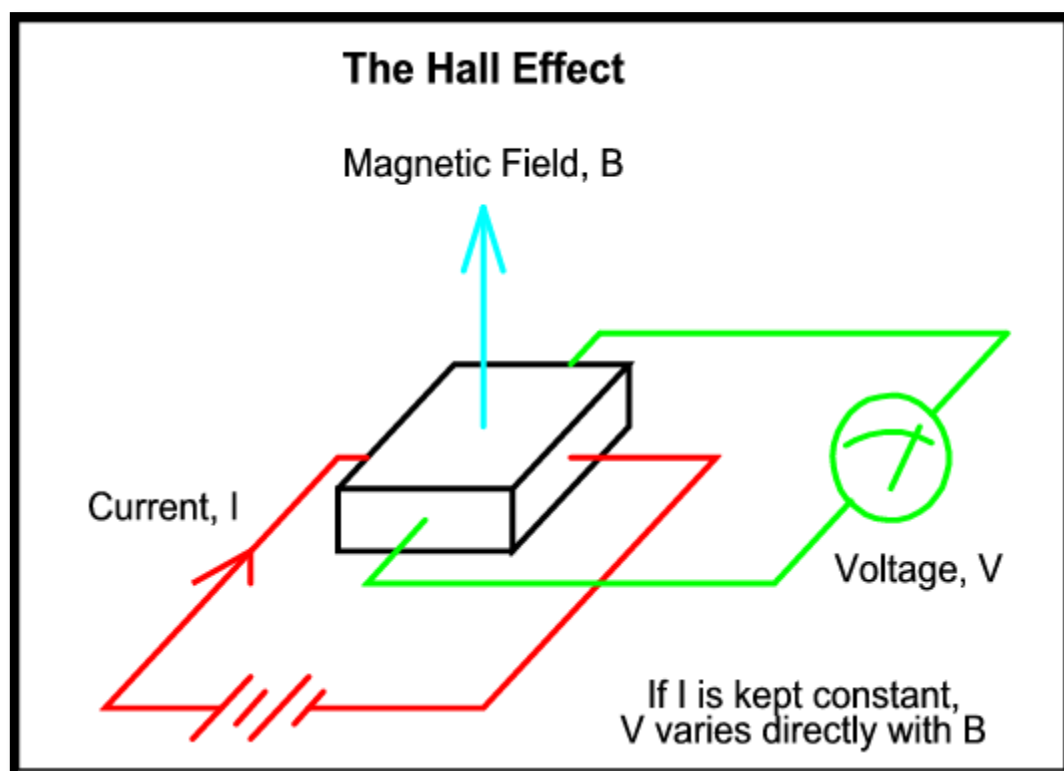


Figure 7 - The Hall Effect induced circuit voltage [13]

Optical encoder

An optical encoder is one of the best methods for calculating the speed for a motor. It can be positioned on a rotating machine away from users and therefore it is safer. Unfortunately because it is built on or next to the machine it is not portable. Notches in a plate that spins with the motor (on the shaft) for measurement can be used to determine speed. Every optical encoder has a light source and a means of detecting it as shown in figure 8 on the top left (two of them).

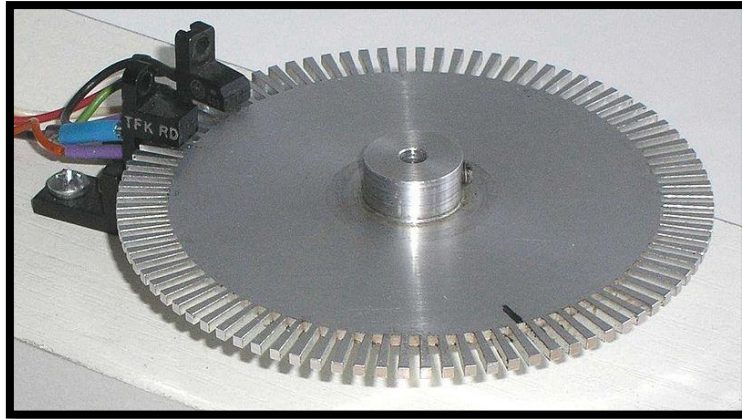


Figure 8 - Encoder disc [14]

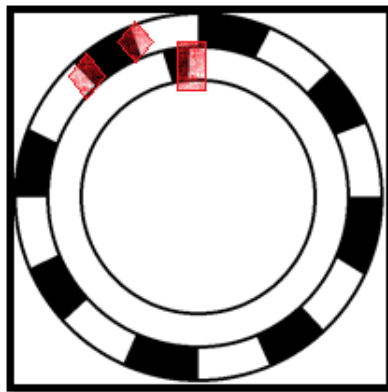


Figure 9 - Visual on and off sequence of encoder wheel

Shown above in figure 8 is what an encoder disc looks like and it has notches cut into it to allow light to pass through and where the material isn't cut out it will block the light flowing. The light passing through will be detected by a sensor and can be thought of in binary as a 1 and when the light is not getting through it can be thought of as a 0, the more notches on the disc the finer the results even at a low speed but at higher speeds the detector might not pick up the light fast enough to give a good rising edge as all sensors have a minimum rise time [15]. Additionally optical encoders are susceptible to dirt or oil that block the light going to the detector as well as ambient light in the environment. More than one detector is needed to calculate direction of rotation and unless calibrated/programmed to count notches for a full turn an additional sensor is needed as the index (which is a notch for a full revolution to be measured). For a very functional encoder 3 sensors can be used for counting revolutions and direction and the way it is setup is shown in figure 9 with the red squares where the sensors would be positioned and where the light and sensors complement each other. In and the output in binary or high and lows is shown what it would look like in figure 10. [16]

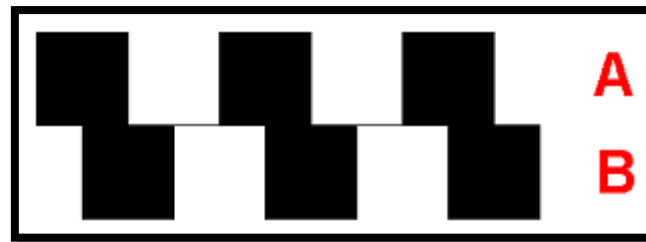


Figure 10 - Sequence of Data

As shown in figure 10 above, when the light is detected it will register on either A or B first. In the illustrated example if the motor is assumed to spin the encoder disc in a clockwise direction the sensor A will register first and then B indicating a forward direction and conversely if B registers first and then A, then it is assumed to be going in the reverse direction or anti clockwise. The third detector or index in this example won't discriminate between forward or reverse direction as it will receive one pulse once the disc has done a full rotation.

Laser and Photodiode

Like the optical encoder this method uses light. A laser is utilized to provide a concentrated beam of light that will reflect off a reflective strip or mirror onto a sensor which will provide a rising edge to measure the speed of an object. The principle of operation is shown in figure 11. At some point as the device is rotating, which can be either a disc on the end of a shaft or the shaft itself, a beam will reflect onto the sensor.

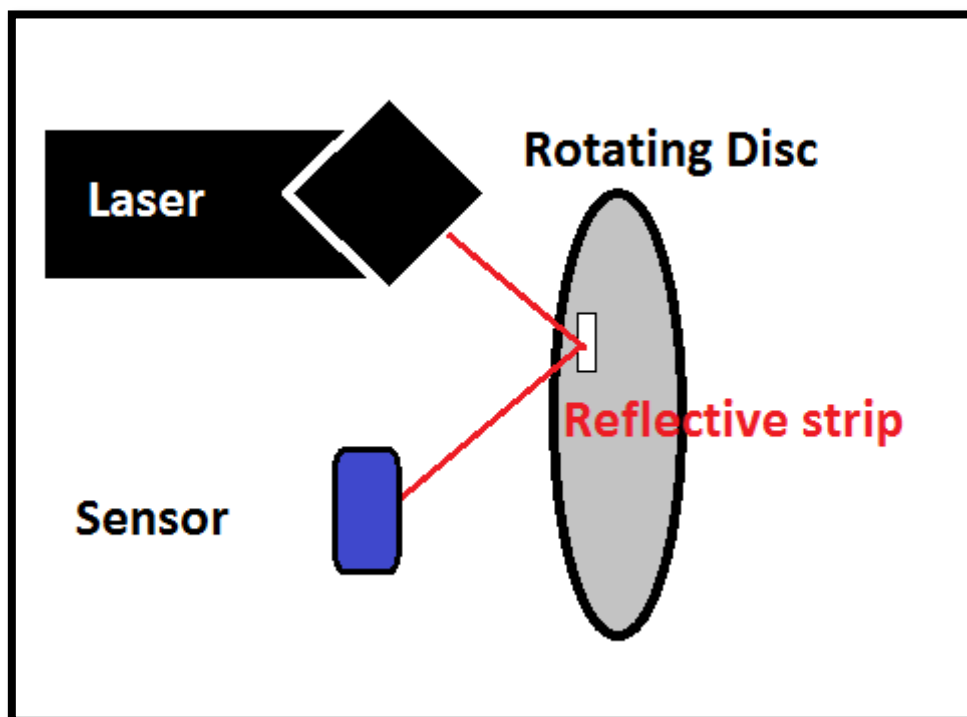


Figure 11 - Laser and reflective strip principle of operation

This method is also (like the optical encoder) subject to losses in light reaching the sensor due to a dirty lens or photodiode but offers safety as it can measure from a distance. Unfortunately to

measure rotation this method could get very expensive as there is a need for more than one photodiode. Again like the optical encoder ambient light can prove to be a problem as it can detect false or unneeded readings.

Laser

The explanation of how lasers work in full is beyond the scope of this thesis but will be briefly explained. Lasers are different to other light sources because of their coherence (how narrow the emitted beam of light is). Light can be generated from a laser in a few ways such as concentrating a light source with a lens such as an LED or passing energy to atoms such as a gas to emit light. The process is shown in figure 12. Energy will be added to an electron increasing its electron energy level (excited), it is unstable at the higher energy level so to lower its energy (relaxes) it releases energy in the form of light (photon). When light is added to an excited electron it produces two photons of the same wavelength of light and phase. This process is contained within a tube with a mirror at one end to bind electrons in a certain direction and they will flow through a lens or series of lenses to concentrate the light. [17]

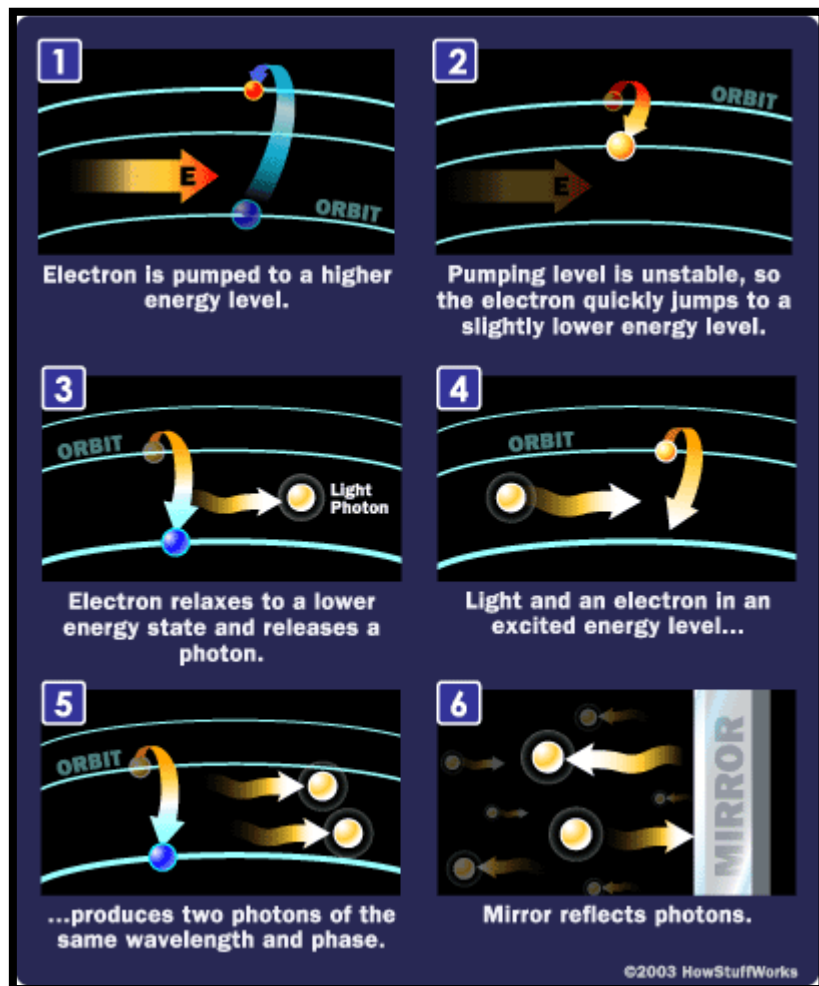


Figure 12 - Description of laser gas excitation [18]

Due to the nature of lasers they can be dangerous and considerations need to be made when designing this project to ensure safety if this method is chosen. Lasers are classed into four general

areas and it is their potential for damage that creates the distinction. A laser should always be labelled in the workplace with one of the four classes:

- **Class I** – class I lasers do not have the ability to emit laser radiation so they should not prove to be dangerous.
- **Class IA** – This class is a special low class laser that isn't made to be looked at but can still be used in places such as super market scanners, their maximum power limit is 4.0mW.
- **Class II** – Low power lasers that are above class II and unless staring at them a person can protect themselves.
- **Class IIIA** – Pen size lasers that can be hazardous and are between 1-5mW.
- **Class IIIB** – Medium power
- **Class IV** – Very high powered lasers around 500mW. Very hazardous and many controls are needed to operate this class laser as they can cause damage and even start a fire. [19]

Photodiodes

The way that LEDs or light emitting diodes work is by passing a current (or electrons) through what's known as an N and P junction. The N type is the negative semiconductor material and P is the positive material. The material (silicon) can be doped by (introducing impurities) either giving it free electrons (or extra electrons) or it can add "holes" or gaps where electrons can flow because silicon has 4 electrons and it bonds with the other atoms perfectly which will not allow a current to flow. The N type material has extra electron and allows for free or extra electrons to flow to a positively charged area. The P type material has extra "holes" and is more positive. When this P type material is excited with a current, then electrons will flow towards the holes, as it travels towards a hole it carries energy and in order to fill this hole it must release any extra energy in the form of light. This process is described in figure 13. [20]

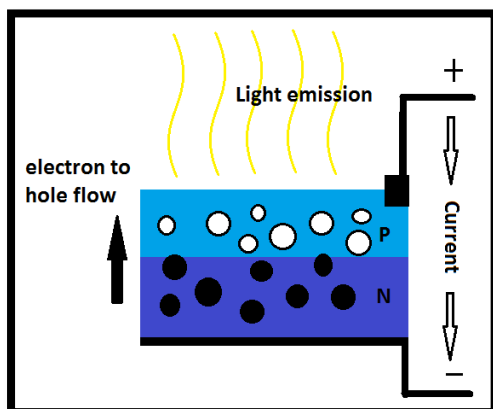


Figure 13 - LED diode emitting light

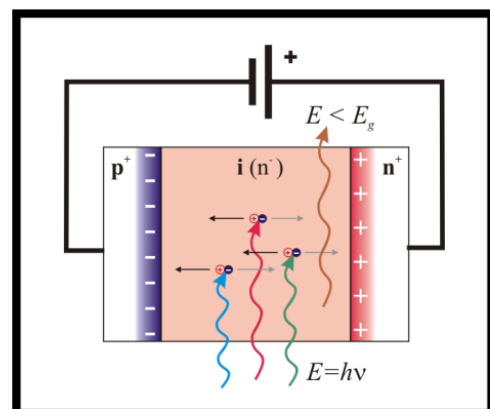


Figure 14 - PIN diode absorbing light [21]

In the case of a photodiode, also known as a PIN diode, it will absorb light and will create a charge [22] refer to figure 14. This ability comes from the "I" (intrinsic) region on the PIN diode. This

intrinsic region is undoped and both holes and electrons can move across this material. The light being absorbed into the intrinsic region can be thought of similarly to the lasers their gas. Photons are absorbed into the material and the electrons get excited and are released and produce a current. This is known as the photovoltaic effect [23] (creation of voltage or current upon exposure to light).

Photodiodes do not discriminate with different light wave lengths and can produce unwanted readings. Shown in figure 15 is a typical response from a photodiode in terms of voltage or current versus the wavelength of light that travels to the sensor.

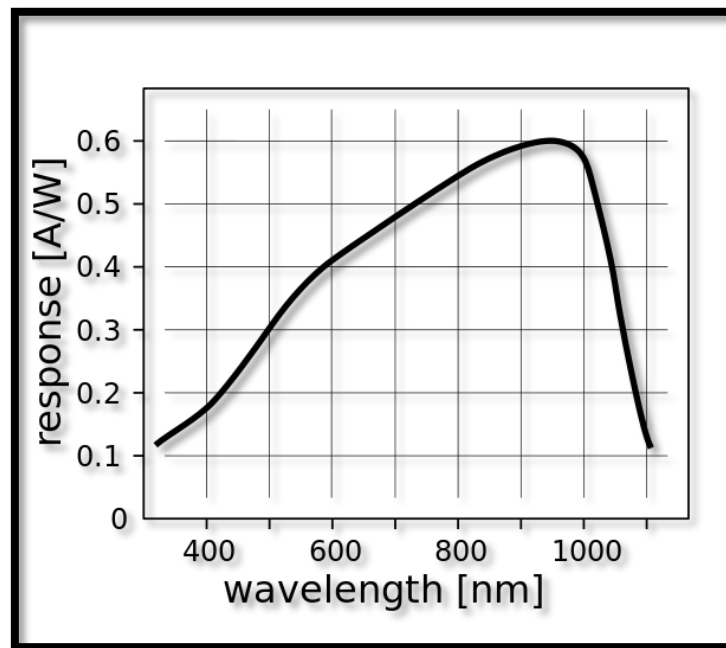


Figure 15 - Photodiode response to wavelength spectrum [24]

For this project phototransistors have also been taken into account but photodiodes are more attractive with their linear characteristics. This means that the more light that comes onto the photodiode the more voltage or current will be produced in a more linear direct correlation type of relationship. Phototransistors which aren't linear will produce a more complex exponential relationship output depending on the input.

3.3 Planning

The first step taken to complete this thesis was to make a Gantt chart. This was done because the project wasn't small enough to just write down short term goals and because of the time critical dates some perspective can be found in when things need to be done. While adding blocks to the Gantt chart, careful consideration was taken in how much time needed to be allocated to each task, cutting and adding effort and focus by reasoning was key here. At this point of the project much of the finer detail was unknown, but the broader objectives could be determined such as expected completion date, general major components of the tachometer device, costs, basic programming directions etc.

4 Designing the Tachometer

From planning it was gathered that what is needed was: a power supply, a form of measurement, a counter, and a way to display results. There is always more than one way to achieve a desired result, this section explains, based on the research and considerations the best parts were chosen.

4.1 Choosing the Right Parts

To be able to choose the right parts the role, performance, efficiency, cost and difficulty amongst others are all taken into account.

- **Energy supply** - The battery for this thesis has to be one that will last a decent amount of time. Enough to power the whole device for a long period of time (about 1 hour) before having to recharge as it will be portable (eg. not plugged into mains power). The simplicity and steadiness of DC power plays a vital role in this project.
- **Power supply** - The smaller components will only be able to run given a certain voltage range. A smaller voltage is required not to damage them.
- **Controller** - A controller of sufficient speed and accuracy is required to send and receive commands swiftly to an adequate degree for everything to run together and smoothly.
- **Measuring equipment** - If something is to be measured then accuracy is needed for good results. The requirement of the thesis is to use "multiple sensors".
- **Display** - A way to display selected information is needed. It is unnecessary to have a large screen but enough to display multiple data. Data can be cycled as well as selected when needed to save space on the screen.
- **Keypad** - One of the measuring equipment components will be a laser, although particularly powerful it is enough to cause damage to an individual's eye. The keypad will act as a security measure where a code will need to be entered to allow use of the laser. Additionally it will be used to change and display different options that can be presented on the display.
- **Programming** – The computer or controller in this project will need to glue and communicate with the other components coherently.
- **Enclosure** - Once all the pieces have been organised, confirmed and tested they will be placed into an enclosure to protect it from dust, moisture and other environmental hazards.
- **Adjustable bits and pieces** - For elegance and good design thresholds and levels can be adjusted, for example the LCD display.

4.2 Energy Supply and Storage

Many energy supplies exist with differing voltages and current ratings. The aim for this project is to make a portable device which can be taken to a motor and calculate its rotating speed. This means that a mains AC supply will not do. A battery needs to be utilized that can supply enough power for periods of time. The perfect battery does not exist, but for this project and its needs, along with future use was taken into consideration. There are hundreds [25] of batteries to choose from and a few more appropriate ones were taken into account before the choice was made. Table 1 is a quick characteristic assessment between the different appropriate rechargeable battery types.

Battery type	NiCd	NiMH	Lead Acid	Li-ion	Li-ion polymer
Gravimetric Energy Density (Wh/kg)	LOW	MEDIUM	LOW	HIGH	HIGH
Internal Resistance (ohms)	LOW	HIGH	LOW	MEDIUM	HIGH
Cycle Life (to 80% of initial capacity)	VERY HIGH	MEDIUM	LOW	HIGH	MEDIUM
Fast Charge Time (Hours avg)	1H	3H	12H	3H	3H
Overcharge Tolerance	MEDIUM	LOW	HIGH	VERY LOW	LOW
Self-discharge / Month (room temperature)	20%	30%	5%	10%	10%
Cell Voltage (nominal)	1.25V	1.25V	2V	3.6V	3.6V
Load Current - peak - best result	20C 1C	5C <0.5C	5C <0.2C	>2C <1C	>2C 1C
Operating Temperature (discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C
Maintenance Requirement	30 to 60 days	60 to 90 days	Occasional Charge	-	-
Typical Battery Cost (US\$, reference only)	MEDIUM	MEDIUM	LOW	HIGH	HIGH
Cost per Cycle (US\$)	VERY LOW	MEDIUM	LOW	MEDIUM	HIGH
Commercial use since	1950	1990	1970	1991	1999

Table I - Comparing 6 rechargeable batteries [26]

Nickel Cadmium (NiCd) Batteries

Nickel cadmium batteries have been around since the 1950s and are therefore a well understood technology. Nickel oxyhydroxide (NiOOH) and metallic cadmium is what makes up the electrodes. These batteries prefer a very fast charge compared to other technologies. Other technologies will generally like shallow discharge and moderate load currents. “NiCad” batteries love to work in the hardest conditions and won’t last long if kept at full charge. It’s very important that a full discharge is performed because if it isn’t then large crystals will form on the plates (also known as memory). Unfortunately these batteries are often overlooked for newer technologies.

Pros

Fast a simple charge, high number of reuses, the highest load performance, can be stored fully discharged, robust – allows for some abuse, low cost, wide range of size and performance abilities.

Cons

Needs to be fully discharged often to avoid memory effects, cadmium is a very heavy toxic metal, relatively low energy density, needs to be recharged after having been in storage. [26] [27]

Nickel-Metal Hydride (NiMH) Batteries

This battery was developed in the 1970s and it was a way to store hydrogen and only developed further in the late 1980s. This battery is very similar to the NiCd battery, for the electrodes, it uses nickel oxyhydroxide (NiOOH) and instead of using cadmium it uses a hydrogen absorbing metal alloy such as a mixture of AB where A is rare earth cerium, lanthanum, neodymium and praseodymium and group B being nickel, cobalt, manganese, and/or aluminium. Nickel hydrogen batteries have up to 40% more energy stored in them compared to NiCd batteries, but are less durable as they cannot do heavy load conditions, be stored at high temperatures and have a high self-discharge.

Pros

Very good improvement in capacity over the NiCd and has potential for even more. Less prone to memory effects and requires less full discharges, environmentally friendly and can be recycled containing only mild toxins.

Cons

If repeatedly deep cycled especially at high currents performance deteriorates, high loads can be detrimental to performance over time, requires trickle charge to avoid generating too much heat, highest self-discharge, to prolong life must be stored at a state of 40% charge and in a cool place. [28] [26]

Lead acid battery (SLA)

Invented in 1859 by French physicist Gaston Planté, the lead acid battery was the first commercially used battery. Today in cars, uninterrupted power supplies, forklifts etc. It was also the first battery that could be recharged by reversing the current flowing through the battery. The first model consisted of two lead sheets separated by rubber strips and rolled into a spiral. During the mid-1970s researchers developed a maintenance free lead acid battery that could operate in any position. Overcharging the battery generates oxygen and hydrogen gas by electrolysis of water so periodic replacement of any water lost is needed, interestingly the electrolyte is more likely to freeze in winter when discharged [29]. Separators are needed in the lead acid battery to stop dendrites from creating a short circuit from plate to plate. Wood was the original separator but the acid electrolyte burned through it. This is why rubber is the perfect choice because it has a good resistance to acid and oxidation while also remaining stable over the battery's operating temperature. In the absorbed glass mat design or AGM for short, the spacer between the cells is

replaced by a mat which is made up of glass fibres and soaked in electrolyte. The mat is to keep the electrolytes from evaporating, while also preventing vertical motion of the electrolyte. When the battery is normally used without AGM the heavier acid molecules settle towards the bottom and this is where the plates get worn out the most so with AGM it eliminates the need to shake the battery, boil it or even run an equalization charge through to mix the electrolyte. Temperature is a major issue and for every 8°C above 25°C the battery life is cut in half. For example a Lead acid battery that would last 10 years at 25°C would last 5 if operated at 33°C and probably only more than a year at 42°C.

Pros

When AGM design is used there is no maintenance other than the very occasional full charge if kept in storage, has a high tolerance to being fully charged, likes to be stored at full charge, low internal resistance making it efficient, very cheap and simple to manufacture, smallest self-discharge compared to others, can handle a high load current, no memory.

Cons

Gas is released when charging voltage is greater than 14.4V. Battery must be kept in a charged state to avoid sulfation which makes the battery very difficult to charge, for longer life must be kept at or below 25°C, low energy density, low cycle life, low energy density, not the most friendly to the environment as it has electrolyte and lead content and also has transport restrictions for flooded lead batteries. [26] [29]

Lithium Ion Batteries

The first work on the lithium batteries started in 1912 [26]. Due to lithium being the lightest of all the metals it has the greatest electrochemical potential and would therefore provide one of the best energy densities per unit of mass. A rechargeable version of this battery was under way in the 1980s but failed because of the dangerous, unstable properties of lithium, especially during charging. A solution was to use non-metallic lithium batteries using lithium ions. With the lithium ion now being safer and slightly lower energy density than that of the lithium metal it's still two or three times the capacity of charge compared to the NiCd batteries. Lithium ion batteries do not suffer from memory and there is no need for scheduled cycling to prolong the battery life. Due to the high voltage lithium batteries only require one cell which makes for a simple and easy design. Unfortunately these batteries are quite delicate and needs a protection circuit to maintain a safe operation such as a voltage limiter from going too high or even too low when the battery's charge is low. In addition to voltage the temperature must monitored, as well as the discharge current being limited to 1 or 2 units or charge above the rated maximum. The battery tends to fail frequently after a period of time due to issues with lithium ion batteries aging.

Pros

High energy density, low self-discharge, low maintenance – no memory or periodic discharge needed.

Cons

Requires a protection circuit, safe until tampered with, limited discharge current, quite prone to aging, expensive to manufacture. [26]

Lithium Polymer Batteries

These batteries are distinguished by the type of electrolyte they use, it is a solid dry polymer. Instead of conducting electricity this plastic like film allows for exchange of ions. The polymer used is safe because no electrolyte is used, very simple in terms of fabrication, and cell thickness can be as thin as one millimetre. The drawbacks are that this polymer has low conductivity and the internal resistance is high, meaning that it cannot give bursts of current as they are required. To improve this a gel electrolyte is added in the cells to improve conductivity which breeds a new name and the proper definition of this battery is a “lithium ion polymer”. It behaves very similarly to lithium ion batteries but offers a little less capacity and presently there is no cost advantage.

Pros

Very low profile (size of a credit card), any shape can be achieved, light weight, improved safety of lithium ion.

Cons

Lower energy density compared to lithium ion, expensive, high internal resistance. [30] [31]

4.3 Power Supply

The 12 Volt battery supply is setup but not all components can handle 12 volts without being damaged. The operating voltage of some of the components has a very slim range generally around 5 Volts so it is important a voltage regulator is built in between the battery and the rest of the circuit. After inspecting the data sheets the voltages required, the components generally needed either 5 Volts or about 3.3 Volts.

- LCD 4.5 – 5.5V input
- Keypad Arduino pin Voltage
- Laser 3.3V input
- Arduino 7-14V input

To lower the voltage from 12 V to a usable voltage there will be power losses in the circuit. Research was done to find the most efficient voltage converter. Out of the researched options one seemed to stand out that would be the most appropriate.

Voltage regulation option 1 – Shunt Regulator

One of the options for the voltage regulation is to have a series of Zener diodes in parallel with the load (the load of course being the rest of the circuit). What this will effectively do is provide a voltage drop across the diode and can be used as a reference voltage. An example of this is shown in figure 16. There is a 12 Volt supply, a resistor and a Zener diode with its “Zener voltage” at 10 volts, and what happens is that the voltage drop across the diode will be 10 and the remainder across the resistor will be 2 volts. The size of the resistor in Ohms will dictate the current through this mini circuit in this case using ohms law its 5mA.

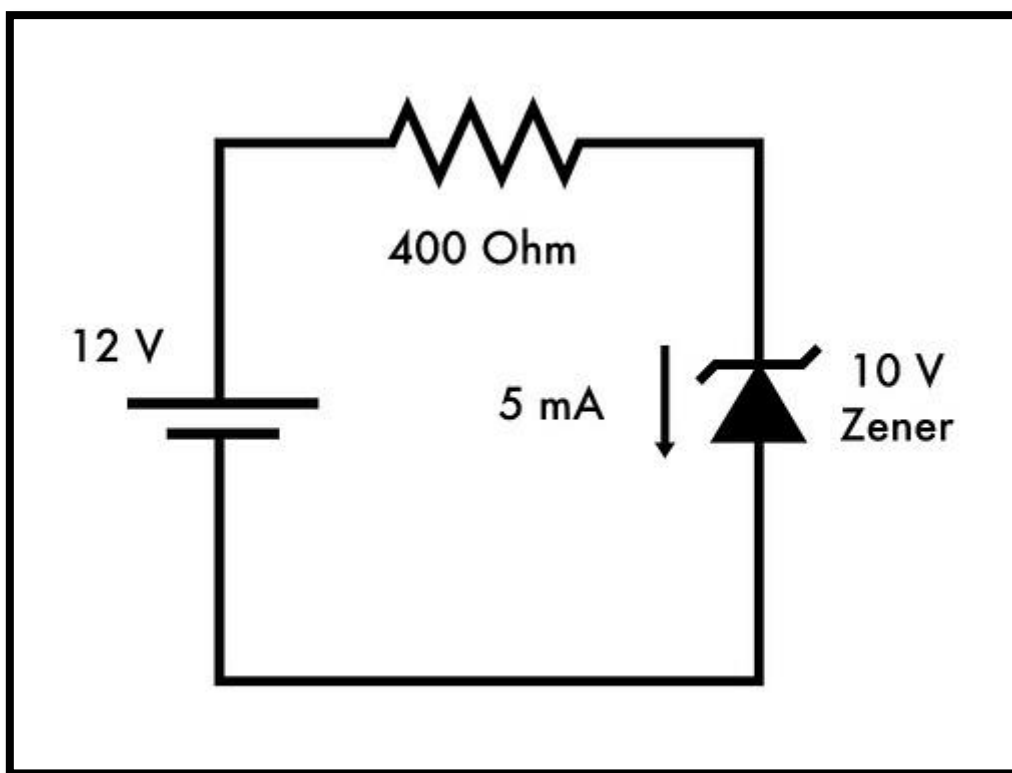


Figure 16 - Simple Zener circuit [32]

The benefits of this circuit is that it is very simple, cheap and it will give the values of the voltage required, however there is a catch. Unfortunately when using the Zener diode as the voltage reference for the output, when the load current is small, the unneeded current from the load will flow through the Zener diode because it needs to go somewhere. If there was no load at all then all of the current would flow through the Zener diode which usually destroys the Zener (depending on its power rating). Furthermore when this Zener is damaged due to excessive power dissipation it will act as a short circuit providing no power to the load and shorting the battery discharging it and risking damage to it and the wires from a high current. A way to limit this damaging current is to get a larger resistor, but now the current will be limited to the circuit which will not be useful if the load demands are high. The only time this setup will work is when the load is drawing a constant current,

which in this case won't be. To illustrate a more intricate example figure 17 describes how a simple circuit behaves with the Zener diode as a regulator (NOTE current arrows are shown as electron flow, not conventional current). [33]

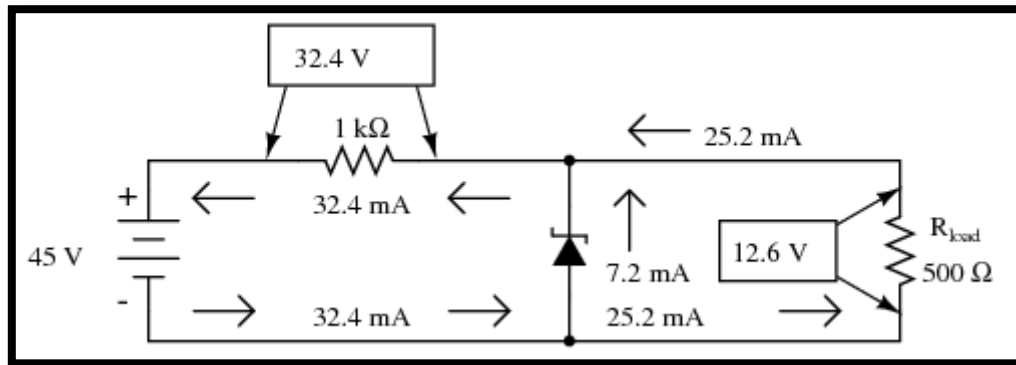


Figure 17 - Zener diode regulator with normal load [34]

The total current flowing in this circuit is 32.4mA. The load cannot draw more current than this value. If the load wasn't there or had a very large resistance then the load would act as an open circuit and all of the current would flow through the diode. In this example the working current is dissipating a safe 408.24mW and generally diodes can tolerate 1 or 2 watts. The larger the resistor the lower the current through the circuit and the safer the Zener diode is eg less power dissipation and lower operating temperatures for the resistor and diode. But it gets to a point where the diode cannot regulate the voltage across the load figure 18 illustrates. (Again current shown is electron flow).

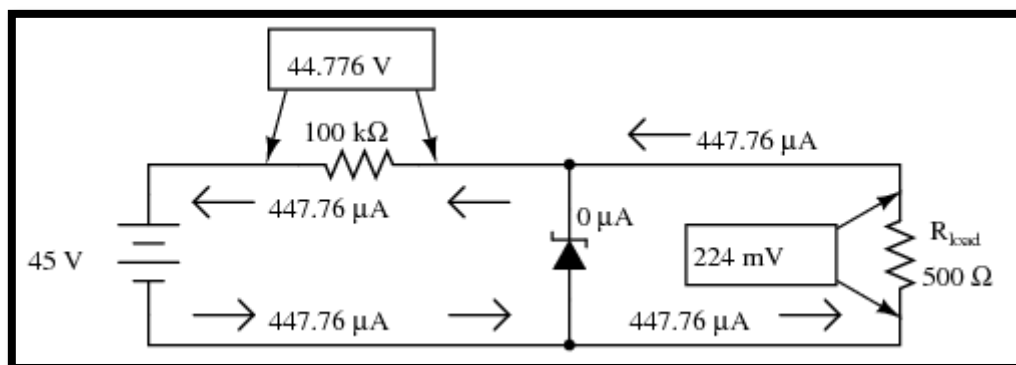


Figure 18 - Zener diode regulator with a large limiting resistor [34]

In figure 18 the voltage drop is mostly across the 100k Ohm resistor. Any Zener diode regulating circuit will only function as long as the loads resistance is equal or greater than a defined minimum value. For example in this circuit it works out to be that the load is 38.889kΩ with or without the diode. If the load resistance value is any larger than the minimum value then that is when the Zener will conduct in to regulate it at the 12.6V as required.

Advantages

A Zener diode can be put in almost any circuit and given its size it is a major advantage where space is limited. Zener diodes are very cheap and easy to setup in a circuit.

Disadvantages

Poor efficiency as the Zener has to constantly have current, even if minimal, running through it. Sensitive parts (could be disastrous if damaged). Limited current supply. This setup involves more maths to calculate thresholds and find that “sweet spot” between current needed and a risky damaging current to the diode.

Voltage regulation option 2 - Linear regulator

The circuit diagram for the voltage regulator option 2 is shown in figure 20.

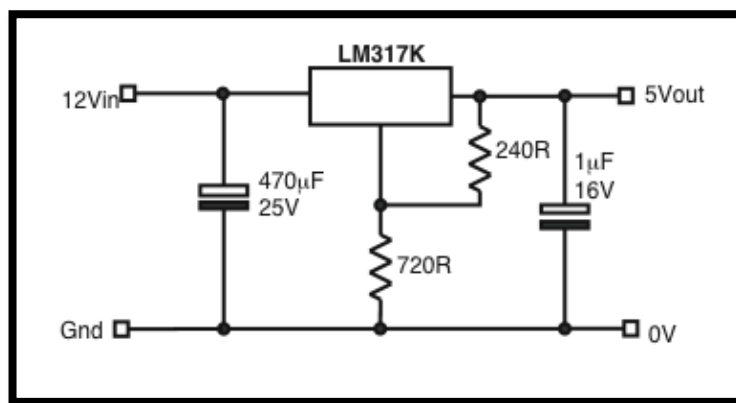


Figure 19 - Linear regulator circuit [35]

Figure 20 - Linear voltage regulator LM317K

Figure 19 shows the part (chip) and it can pack a punch given that its operating temperature can go up to 125°C. Linear regulators are very easy to setup just like a parallel Zener diode except there is more control and it can pass a larger current through it (1.5A with adequate heat sinking or 20W of power dissipation). [36] The voltage output is regulated by a ratio of two resistors; here it is shown as 240 and 720 ohms which will yield a 5 Volt output and works like a feedback controller. The capacitors involved in this circuit are just used for transient stability. Seemingly perfect, this design is flawed because it needs to dissipate 12 W and a large heat since that is rated at 2°C/W or better. Lots of heat dissipation also means lots of current wasted and is only about 42% efficient. [35]

Advantages

Simple design consisting of 3-5 parts. Can handle a large current at 1.5A and can operate up to 125°C. Linear regulators don't produce noise in the output. Fairly small design allowing it to fit into most circuits.

Disadvantages

The referenced 42% efficiency is quite terrible. Needs a minimum of 5-12mA on the load.

Voltage regulation option 3 – Switching power supply

The third option is very similar to option two in that there is a resistor ratio that defines the output voltage, except this time the current is not constantly drawn but there is a type of “checker” for the output voltage. This circuit constantly checks and compares the output voltage to the desired voltage output. Figure 21 shows the working circuit for the selected switching frequency power supply and it is 88% efficient. [35] Generally switching power supplies can obtain between 70-90% efficiency and the more the voltage has to drop the less its efficiency. The Schottky switching diode is accountable for most of the losses. If the circuit is under 10V for example about a 4% loss is applied if the output is 12V and a 10% loss if it's at 5V. [37]

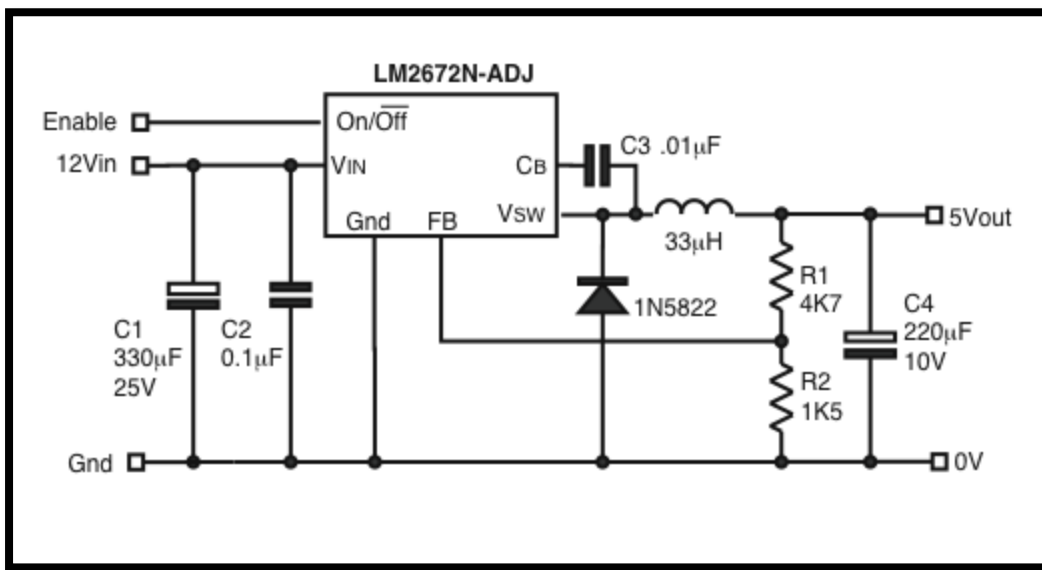


Figure 21 - Efficient switching power supply circuit [35]

This circuit is very attractive as it is very efficient because even if nothing is connected it will only draw 3.4mA which is incredibly small. This circuit is robust in the fact that the input can be a large range from 5V to 40V. The only disadvantage is that the output is not a DC output which can be resolved later on.

Advantages

Very efficient at 88%. Small current draw when there is no load. Quite a robust and flexible design. Provides a large current (around 2A).

Disadvantages

A large amount of parts which might not be readily available are required to build this circuit. Average difficulty in setting up. The parts can get quite large if trying to conserve space.

4.4 Micro Controller

Not any micro controller can be used for this device. Controlled readings are required for accurate results. Also the more frequent the readings the more accurate the results will be. The choice of a micro controller is between a Raspberry Pi and an Arduino.

Measurement

Figure 22 demonstrates a signal and how a computer can take a measurement and have error in the reading. The signal is series 1 on the graph and the impulses of series 2 are when the device checks for a measurement. For a device to perfectly measure an event it would instantly take a reading as it happened. This is not the case as an event will occur and the computer will check periodically to see if anything has happened.

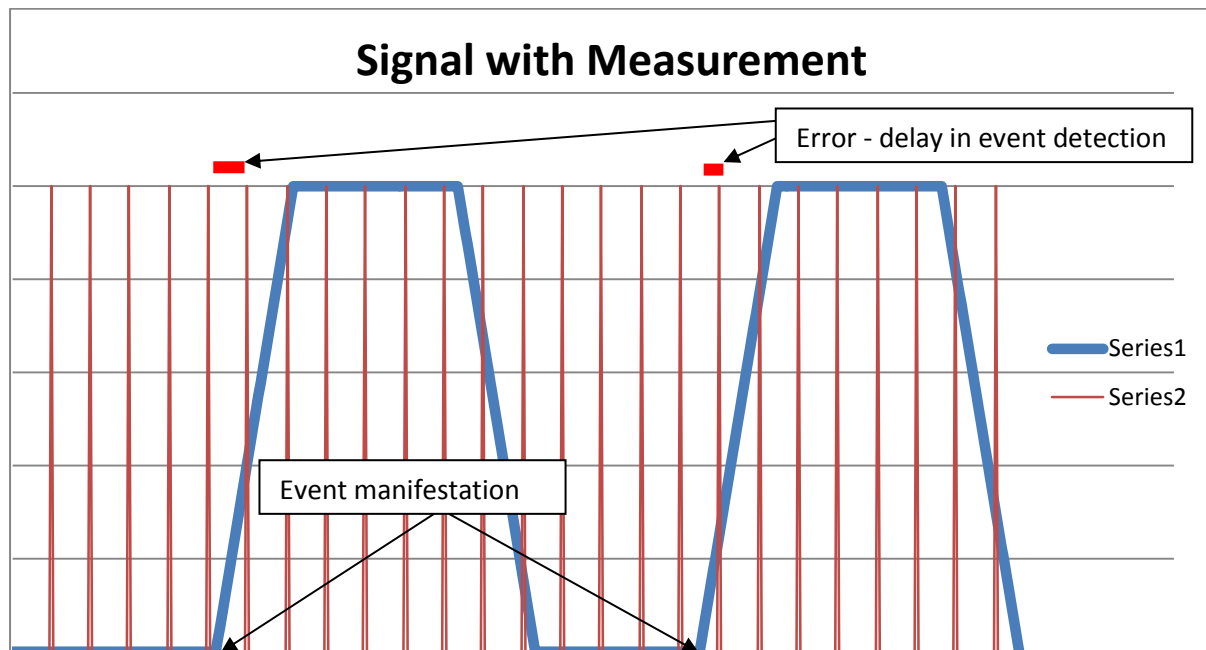


Figure 22 - Measuring Rising Edge

Cooperative vs. Pre-emptive programming

Pre-emptive Programming

Many operating systems such as Microsoft Windows, Linux, Android etc. support pre-emptive programming. This style of programming is how the operating system deals with commands and tasks, which is splitting them into more manageable pieces so that the processor can execute those bits at a time (called threads). The period for which a processor dedicates its resources to one thread is called a "time slice" or "quantum". This gives the illusion that the system is multitasking. The benefit of this is when there are a lot of tasks that need attention it is guaranteed that each will get a time slice and the processor unless specifically directed by a scheduler. The operating principle of a tachometer is that a signal will occur (event) and the idea is for the code to be temporarily interrupted to give attention to an event and process the data (called interrupt handling). With any system design certain kernel functions or service interrupts, if not allowed to "run to completion" (which fully finishes a task and gives control back to the scheduler) will produce something called a race condition [38]. A race condition is where the system is dependent on timing of other

uncontrollable events and becomes a bug when the events do not happen in the order that the programmer specifies and two signals are “racing” each other to influence the output first. Each signal blocks the other leading to deadlock. The Raspberry Pi is based on a Linux system which is pre-emptive. [39]

Cooperative Programming

The Arduino runs a cooperative programming scheduler [40] that switches from one task to another. This means that a task will execute from start to finish without jumping to another task like a pre-emptive scheduler. Because of this the programmer must implement interrupts to do a critical task if there is one, which in the case of the tachometer there is when a signal comes through. Cooperative programming has fewer re-entrance issues [41], which is what happens when an interrupt occurs; the code might not increment a value correctly for example. As a consequence of this care must result in correctly programming interrupts so that they do not take up a lot of the processor’s time away from functions. [42] [43]

The Microcontroller for this project

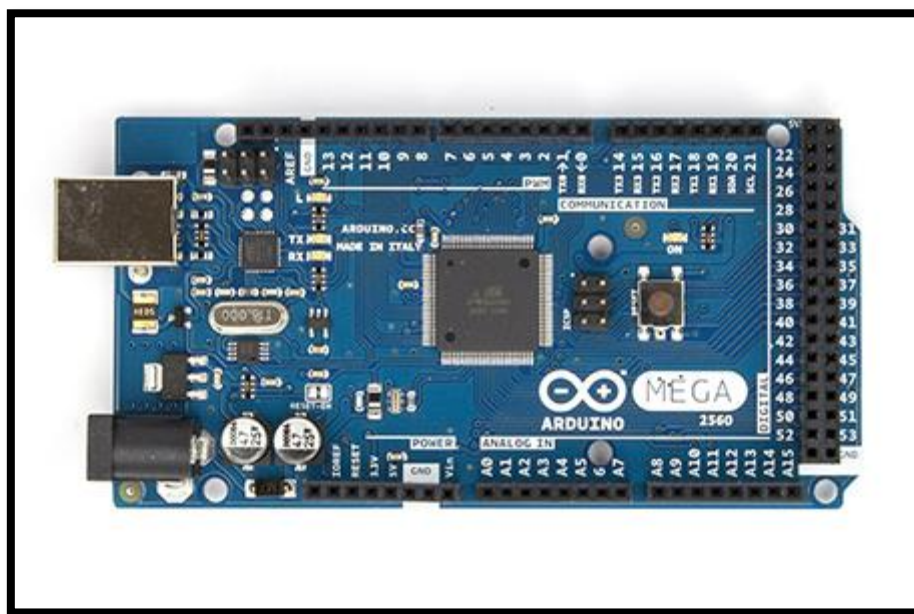


Figure 23 - Arduino Mega 2560 board [44]

This project will use the Arduino Mega 2560 model, shown in figure 23. It has a fast clock speed of 16 MHz, which is important for high resolution time measurements, 54 digital pins which is plenty to communicate with the other equipment that run at 5V and can sink 40mA if required. The input voltage is between 7-12V which can be directly connected to the battery for initial testing, and there are a lot of libraries which will support this project and its code for coherency on the Arduino website (Arduino.cc).

4.5 Measuring Equipment and Sensors

This project will be using two ways to measure the speed of a rotating device: the Hall Effect sensor and A laser with complimentary photodiode.

Hall Effect sensor

The Hall Effect sensor mentioned in this report is the Freetronics model AH180 [45] shown in figure 24 on the left with a generic magnet on the right for testing.

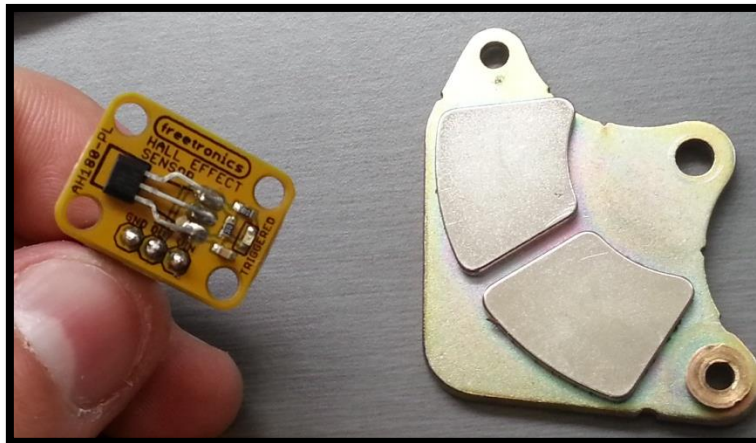


Figure 24 - Freetronics Hall Effect sensor and generic magnet

This sensor has a very short rise time with a maximum period of only $125\mu\text{s}$. The supply voltage for this device is 2.5 to 5.5V with a maximum current draw of 6mA if the voltage is 3V which makes for low power operation. [45]

Laser and photodiode

The photodiode used in this thesis is model S5107 with a cut off frequency at 10MHz, which is sure to give a good fast response and rising edge. [46]

A green laser model COM-09906 will be used to this project. It is 5mW with a wavelength of 523nm. The power input is 3.2V and consumes less than 300mA the point or dot at 6 meters is 18mm with an error of 2mm. A stand has also been added to the laser (and mounted) to adjust for angle both shown in figure 25. The negative terminal is the spring and the positive terminal is the brass casing. By the standards this is a class IIIA laser. [47]

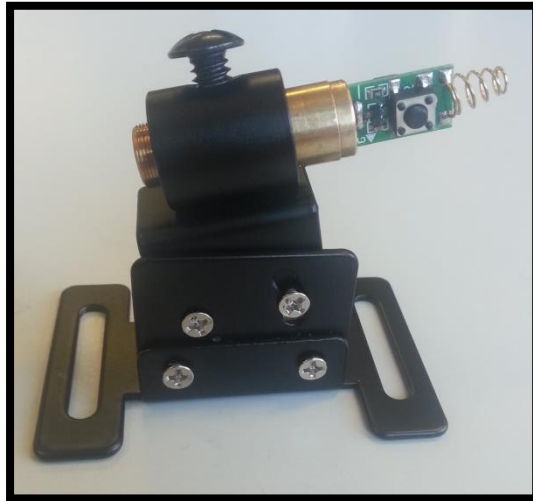


Figure 25 - Laser and mount

4.6 Display

The display chosen for this thesis is an LCD screen that is 16 character spaces by 2 lines which should be sufficient for displaying all the data required (a value in radians per second or revolutions per minute and to save space there will be options to choose between them). The LCD in question is the model Z7011A [48] with the LCD driver (logic processor) as SC1602H and it is displayed in figure 26.



Figure 26 - Z7011A LCD screen

This LCD needs to be powered at about 5 Volts with the minimum voltage being 4.5 Volts and a maximum expected voltage of 5.5 Volts and this will power the driver to process data on the logic level to make the LCD work. According to the data sheet the LCD driver will draw 6mA maximum and a typical current is 3.2mA. To trigger the pins as a binary input or high there needs to be at least 2.2 Volts and a maximum voltage must be the same voltage supplied to the LCD driver, as for the low or binary 0 for the data the pins must be between 0 Volts (ground or reference) and 0.6 Volts maximum. [48]

The pins shown in figure 26 running from left to right are numbered in table 2 below:

14	13	12	11	10	9	8	7	6	5	4	3	2	1	15	16
----	----	----	----	----	---	---	---	---	---	---	---	---	---	----	----

Table II - Pin out table for LCD screen (front)

Their functions can be described in table 3 below

Pin number	Function
1 Vss	Supply ground
2 Vdd	Supply voltage
3 Vo	Contrast adjustment
4 RS	Register select
5 R/W	Read/Write
6 E	Enable Signal
7 DB0	Data bit 0
8 DB1	Data bit 1
9 DB2	Data bit 2
10 DB3	Data bit 3
11 DB4	Data bit 4
12 DB5	Data bit 5
13 DB6	Data bit 6
14 DB7	Data bit 7
15 A	Supply voltage for the back light
16 K	Supply ground for the back light

Table III - Pin out description for LCD screen

5 Volts and ground needs to be supplied to pin 1 and 2 first and foremost for the LCD driver to work. The contrast of the LCD can be adjusted with pin 3 with a variable voltage between 0 and Vdd. The register select allows for a controller (such as a micro controller) to select which space the LCD screen will write to which is pin 4. It is possible to read back from the LCD to a controller which is what pin 5 allows (0 is write, 1 is read). Pin 6 is the enable pin which connects to the controller and communicates when the LCD screen is ready for data input (the rate at which the LCD driver can receive data is about 37 μ s, per pin). Pin 7 to 14 relates to the data input of 8 bits. 8 bits of data are uploaded to the LCD screen at a time to show different characters on the screen such as writing (starting with data bit 7 with to 0) "00100110" will show "b" on the screen.

Different functions such as activating a blinking cursor, clearing the display of data, returning the cursor to the start position (normally move left or move right) can all be uploaded as a command through the data pins. [49]

4.7 Keypad

The keypad used in this project is model S5381 shown in figure 27. The reason why this keypad is used is to have the user for this device put in a password before the laser is activated due to the dangerous nature of them. The keypad is also used to cycle through options when the device is running to display different things. The keypad has no driver like the LCD screen but is a set of wires and switches in a matrix so when a button is pressed it will close the circuit and be able to conduct electricity for signals.



Figure 27 - Keypad, model S5381 [50]

The pinout and matrix with the buttons is shown below in figure 28. It describes the relationship with each button to the pins of the keypad for example if button “1” is pressed then pin 3 and pin 4 is connected or if button “8” was pressed pin 7 and pin 2 would be connected to each other. This process was discovered through using a multimeter and setting it to the short circuit function to see if the connection was made through pushing buttons in sequence and writing them down on a piece of paper. [51]

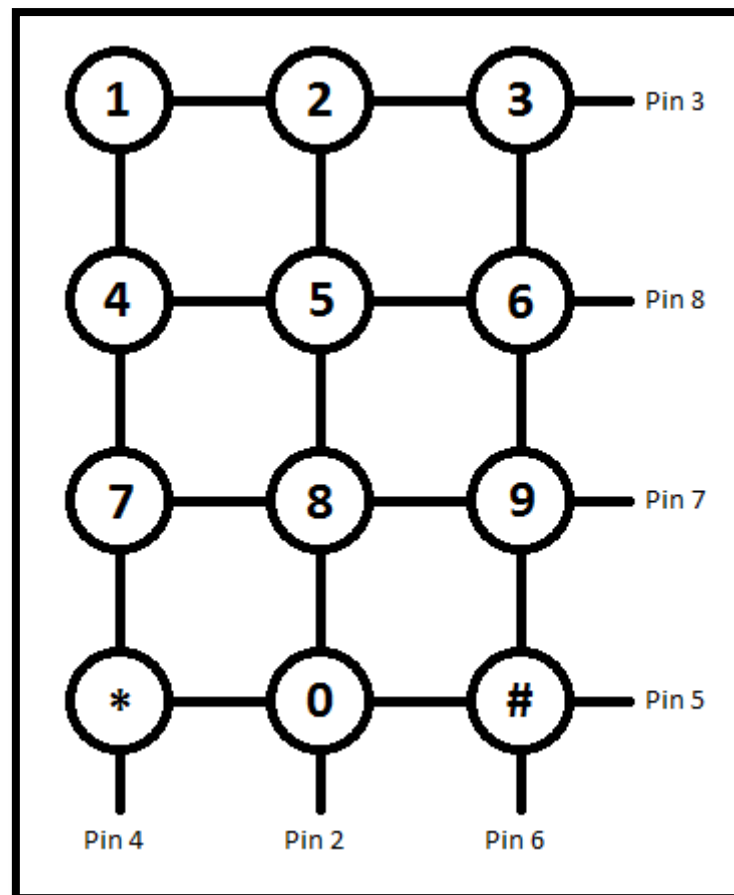


Figure 28 - Keypad matrix pinout

4.8 Programming

The Arduino microcontroller has a set of commands (computer instructions) that it runs and it is the “glue” for the physical components for this project. It is beyond the scope of this thesis to explain assembly language or machine code, which is the final form of what a program looks like before it is run by a computer. This final form is the lowest language possible because it is described to be “close to the hardware” but a high level program will be used and explained how it gets there. [52]

Programs are written by programmers in a certain language, in this case a combination of C and C++ [53] and there are many other languages to write in. This is called the “source code” and it is designed to assist the programmers in making the computer instructions more readable and easier to work with. The IEEE define source code as any code that can be a fully executable system and construed to have machine code, high level languages and executable graphical representation of systems. [54]. When the source code is completed it needs to be compiled (converted) into instructions called assembly language or machine code so that (in this case) the microcontroller knows what to do. This compiler is called the Arduino IDE. [55]

The Arduino IDE executable program (opened through the Microsoft Windows operating system) used in this thesis is called “Arduino” when installed on the computer. It was written, debugged and supported by Massimo Banzi, David Cuartielles, Tom Igoe, Gianluca Martino and David A. Mellis [56]. The version used in this thesis is 1.0.6 and supports many different Arduino boards except for the Arduino Yún and Arduino Due.

There are three main parts when programming an Arduino program called a “sketch”: Structures, Variables and Functions. [57] A sketch might also refer to a “library” [58] which gives extra functionality by adding pre-existing functions and variables to use. Because the Arduino’s software is open source and many of the authors that post libraries declare them as free software, it will make programming this project a lot shorter, neater and easier. This is declared in every library used and stated that it can be modified under the GNU Lesser General Public License published by the Free Software Foundation. [59] [60]

Structures are at the very top level of a program’s code. They are responsible for grouping together variables and functions and telling them when and how to execute. For example the two main structures in the Arduino code is “setup()” which runs one time to setup things before the main program and the other is “loop()” which is responsible for running the main code and as is suggests runs in a loop constantly repeating executable code. There are smaller structures (called control structures) such as: if, for, while, break, goto, return etc which does things in a certain way. For example the “if” control structure will compare something such as if value “x” is bigger than value “y” then do something otherwise that part of the code will be skipped. Generally the program that is made by the programmer will be interpreted like a book by the Arduino IDE and it will sequentially run from the start of the program to the end like a list each line one by one until it has to loop again and any code that has been skipped, if the condition isn’t met, will be skipped again. [61]

Variables are stored values and something quantitative that the microcontroller can use for comparison and refer to many times. It makes it easier for the programmer to refer to because it is easier and more understandable to include a variable whose value is 10 rather than writing 10 many times in the code. Values can be in the form of a “HIGH” or “LOW”, true or false, Boolean, byte, word, long, array etc. known as data types, a table of all types of data used for the Arduino and its purpose is located in the appendix. An example of this is the line below called a declaration.

```
int pin = 7
```

The simple code above just declared in the code as the variable “pin” to have a value of 7 and the data type to be in the form of an integer (int). [62]

Functions break up big code into smaller manageable chunks, keeping the code neat and tidy in the process. A function will perform a specific task where it has to be used more than once in a program. For example the pseudo code below demonstrates physically bringing a voltage on a micro controller high (to 5 volts) and low (0 volts)

```
digitalWrite(10, HIGH)
digitalWrite(10, LOW)
```

This code would turn the corresponding pin on the Arduino Mega to high which is pin 10. Because earlier the variable “pin” was declared to be 7, pin 7 can be brought up to a high by typing:

```
digitalWrite(pin, HIGH)
```

There are many more different examples of structures, variables and functions on the Arduino website “Arduino.cc” [63]

5 Building and Testing

When building anything it needs to be broken up into smaller components. These components are like building blocks for a house. Each block must be inspected and tested before they are placed otherwise the house crumbles. The blocks for this project have been broken up into stepping stones and these were the steps taken: LCD screen, keypad, power supply, Hall Effect sensor, laser and photodiode, final programming, and final testing.

5.1 LCD Screen

The LCD screen needs to be tested before further testing can take place as it will serve as a communicator or indicator for debugging other components. To setup the LCD, the pins on the LCD need to communicate with the pins on the Arduino. Checking is part of the method; since the LCD runs at 5 Volts and the Arduino pins are also 5 Volts while also providing up to 40mA so it is safe to connect. A library developed and provided by Arduino called LiquidCrystal will be used as will help run the LCD driver. The first thing that needs to be done with the sketch is to setup the pins. A constructor will set up the pins such as the one mentioned on the Arduino website:

```
LiquidCrystal(rs, enable, d4, d5, d6, d7)
```

The line above is called a syntax which will setup a: register select, an enable pin and 4 data pins. For this project the Arduino used has many pins to use and the full syntax can be used which is the line below:

```
LiquidCrystal(rs, rw, enable, d0, d1, d2, d3, d4, d5, d6, d7)
```

Added is the read/write pin which means both read and write can take place (the default low is write) and 4 additional data pins which means that in one clock cycle the Arduino can upload all the data for one character. In the sketch the code looks like the line below:

```
LiquidCrystal lcd( 50, 48, 46, 44, 42, 40, 38, 36, 34, 32, 30);
```

In this case "lcd" is the object and can be called later in the code for use. "LiquidCrystal" is a reference to the library and looks for a similar amount of inputs, which in this case is 11 numbers which correlate to 11 pins on the Arduino. The "rs" or register select pin on the Arduino is now addressed to pin 50, read/write is pin 48, enable pin is 46 and the data pins are even numbers from pins 44 to 30.

During the starting phase of the Arduino microcontroller turning on it runs the function setup() and inside this function to clear the screen ready for use 3 things must be entered shown on the next few lines:

```
lcd.begin(16, 2);  
lcd.clear();  
lcd.setCursor(0,0);
```

lcd.begin(16,2) - indicates that an LCD will be used and that there are 16 columns and 2 rows.
 lcd.clear() – clears the screen of any memory that the LCD driver has displayed on screen
 lcd.setCursor(0,0) – and finally this line puts the cursor at the origin point which is the top left corner of the screen ready for displaying letters.

Simple code is used to test to see if it works and is as follows:

lcd.print(“RPM:156”) and the LCD prints or displays the message on screen as indicated in figure 29.



Figure 29 - LCD with data displaying

5.2 Keypad

The keypad as mentioned before is connected up as a matrix with the pins and it is safe to directly connect the pins to the Arduino. There are 12 buttons but only 7 pins. Once the columns and rows are identified with the corresponding pins, a program will need to keep checking to see if a button is being currently pressed, rather than waiting for a button to be pressed as the program will stop working if it is waiting for a condition to be met. A keypad library made by Mark Stanley and Alexander Brevig (citation in library) called Keypad has simplified the process. This keypad library communicates with the sketch and is compiled when uploaded to the Arduino when it comes to running it. Not all the functions are used from the library, but the main functions that are will be mentioned and explained.

One of the functions in the library is called the constructor and it sets up the columns and rows with the designated keys and the pins that are associated through arrays and a matrix.

The constructor (in the library): Keypad::Keypad(char *userKeymap, byte *row, byte *col, byte numRows, byte numCols)

The function in the sketch: Keypad keypad = Keypad(makeKeymap(keys), rowPins, colPins, rows, cols);

“Keypad” is a function in the library which “keypad” with a lower case is a global variable, which means it can be used anywhere in the sketch when it is “called”. The constructor requires many

variables such as: “rows” and “cols” which an array that contains where the pins are physically put into the Arduino. This code is described below:

```
const byte rows = 4;
const byte cols = 3;

byte rowPins[rows] = {4, 9, 8, 6};
byte colPins[cols] = {5, 3, 7};
```

“const” stands for constant and cannot be altered like other variables. Lastly to setup the keypad custom keys can be setup so that if the key “1” is pressed something else of the users choosing can be used. In this case the program will interpret each key for what it originally stands for.

```
char keys[rows][cols] = {
  {'1','2','3'},
  {'4','5','6'},
  {'7','8','9'},
  {'S','0','H'}
};
```

The keypad is now setup with everything connected physically. Next some code is setup to display whatever key is pressed on the LCD. The code is as follows:

```
char key = keypad.getKey();
lcd.print(key);
```

The keypad library is referred to with the “getKey()” function. This will check to see firstly if a key has been pressed and if it has what key is it? Once the buttons data has been deciphered then the information (value) is stored in the variable “key” as the data “char” or character. After this process is finished the LiquidCrystal library is called to display the character on screen.

5.3 Power Supply

The switching power supply based of figure 30, once built, provides 5V of power and its circuit is below shown in appendix X.1 and provides an output illustrated in figure 31 and with a 1000uF capacitor it looks a lot better shown in figure 32. Figure 33 shows the circuit for the linear voltage regulator needed for the laser which runs at around 3.3V, the circuit used in the thesis is described in appendix X.2.

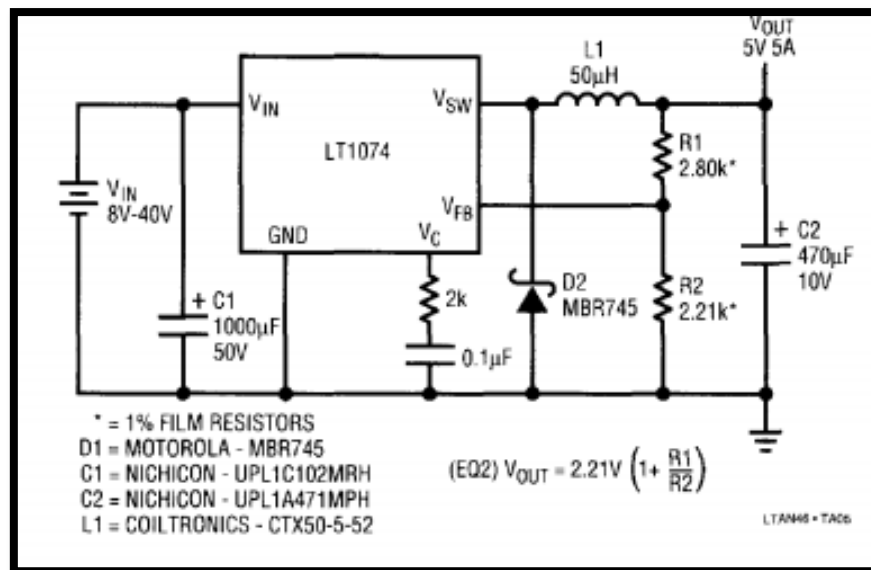


Figure 30 - Developed circuit from this diagram [37]

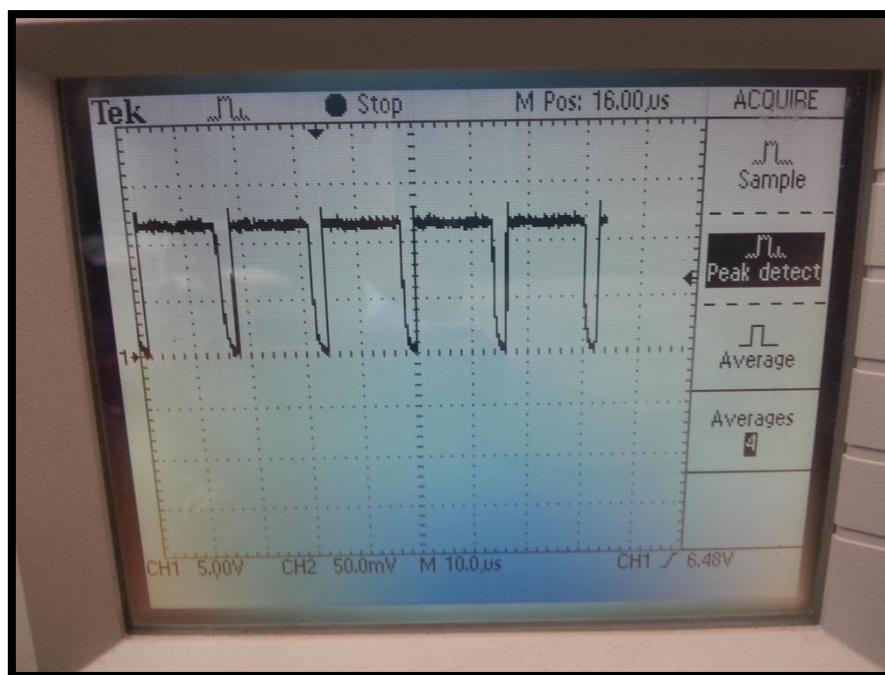


Figure 31 - Switching power supply without capacitor

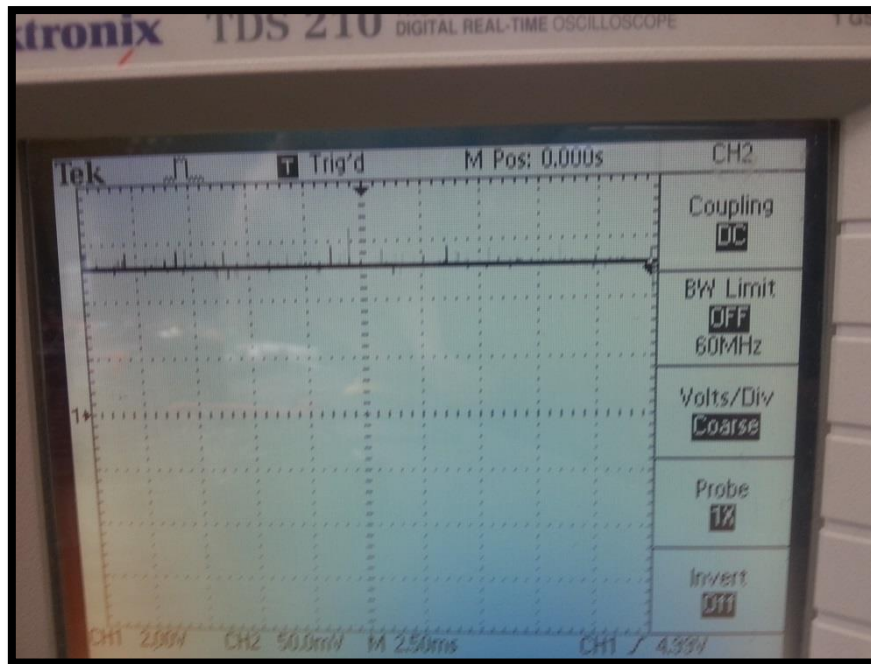


Figure 32 - Switching power supply with capacitor

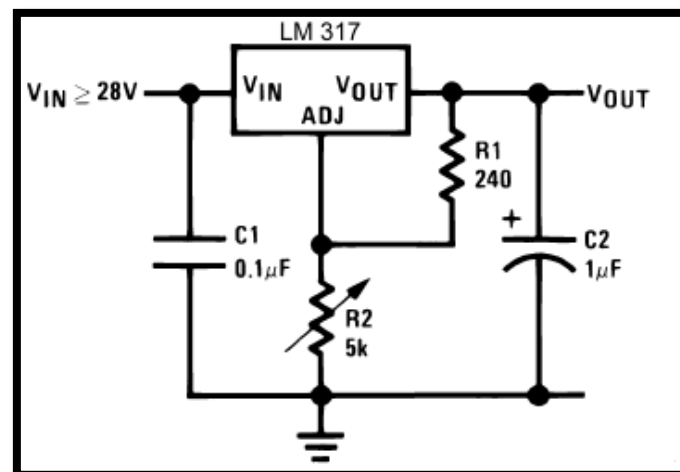


Figure 33 - Adjustable Linear voltage regulator [64]

5.4 Hall Effect Sensor

The Hall Effect sensor once placed near a magnetic field provides a very good rising edge which is perfect for measurement. The signal is shown in figure 34 when connected to an oscilloscope. The Hall Effect sensor needs a ground, supply voltage, and the signal output when turned on will provide a falling edge which is important and will be explained later. The operational range is between 10-60 Gauss (can be more but unnecessary) [45]

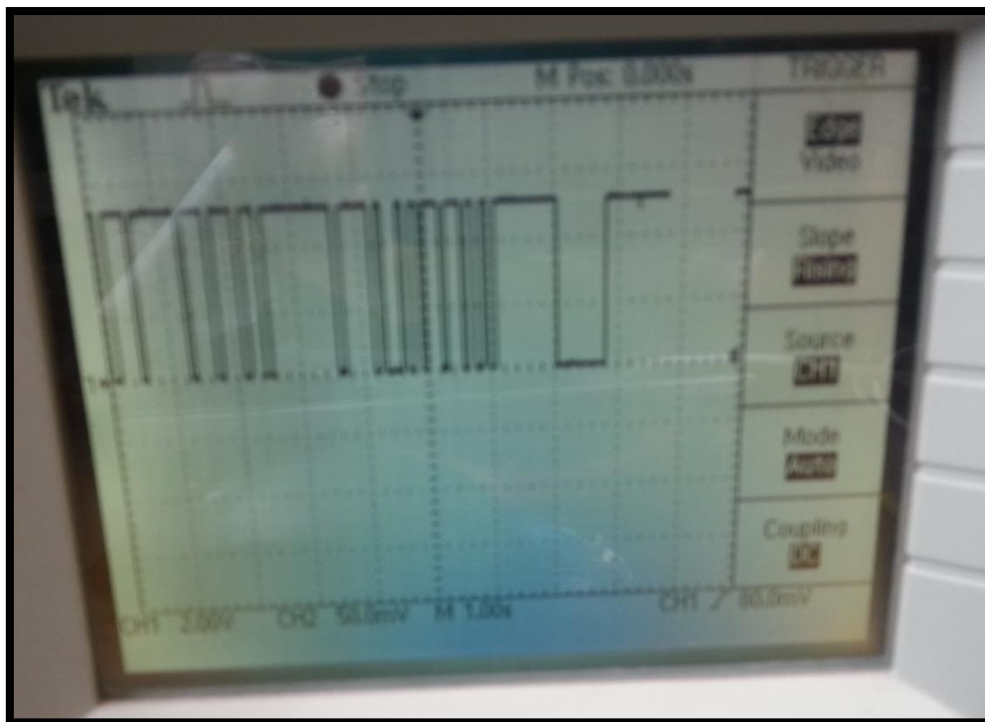


Figure 34 - Hall Effect sensor displayed on the oscilloscope

5.5 Laser and Photodiode

When the positive and negative terminals of the photodiode are connected to an oscilloscope it produces a DC like voltage shown in figure 35. The screen reads about 420mV when ambient light from the room excites the photodiode and when it is being covered crudely some light still gets through registering about 200mV illustrated in figure 36.

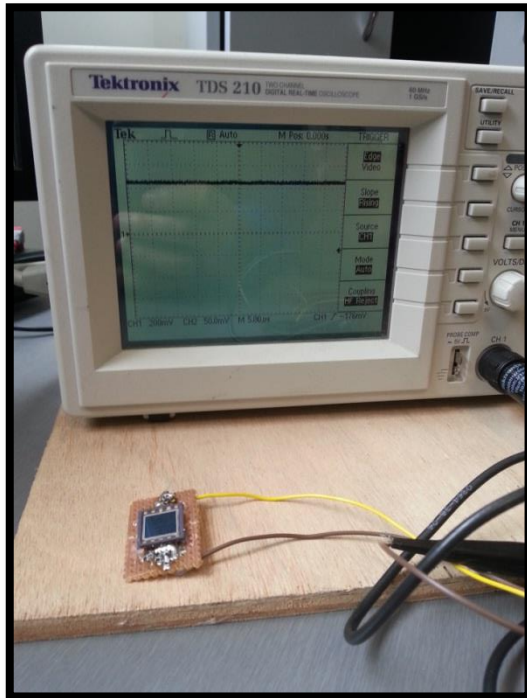


Figure 35 - Covering the photodiode

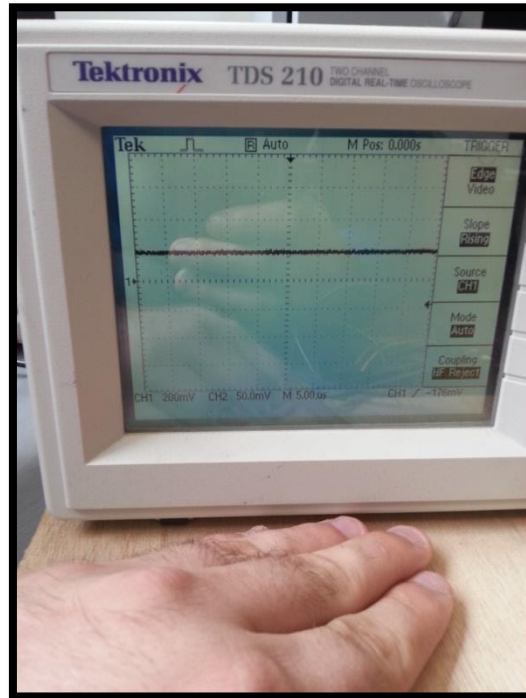


Figure 36 - Raw input from Photodiode

The activated laser when powering it with 3.3 Volts is shown in figure 37 with the photodiode still produces a little more voltage with the oscilloscope. After some testing it is concluded that the maximum output for the photodiode is 500mV which could prove to be a problem because it might not be enough for a good strong signal. Additionally figure 38 shows the output of a slightly noise signal from the photodiode which is quickly fixed by a 10 μ F capacitor being put in parallel shown in figure 39, and keeping in mind if the capacitor is too big then the rise time increases due to its capacitance so this one was kept low. [65]

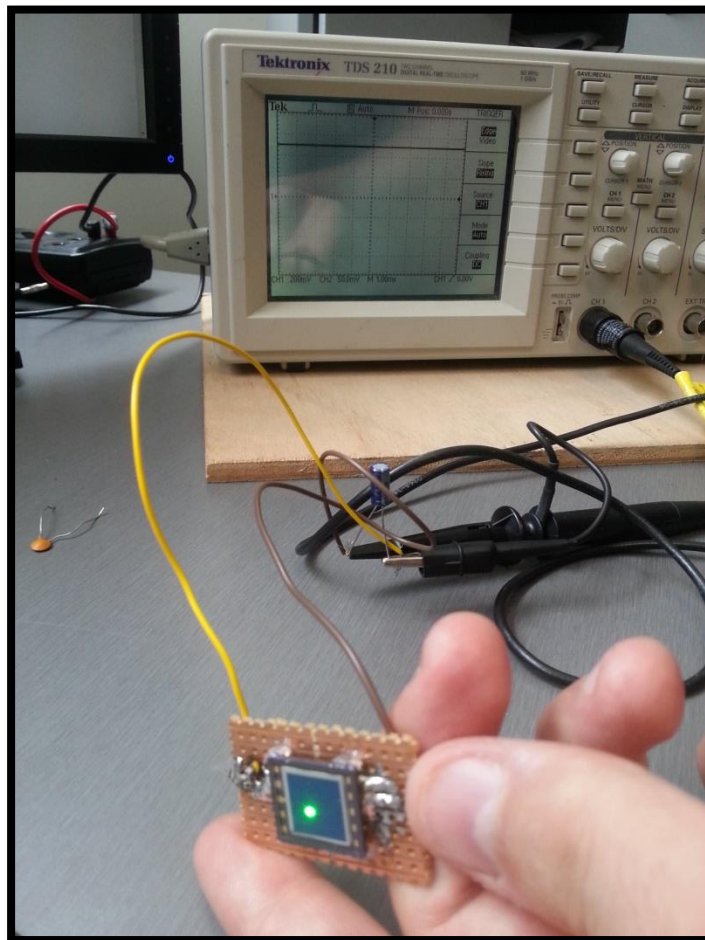


Figure 37 - Producing voltage with the laser



Figure 38 - Photodiode without capacitor

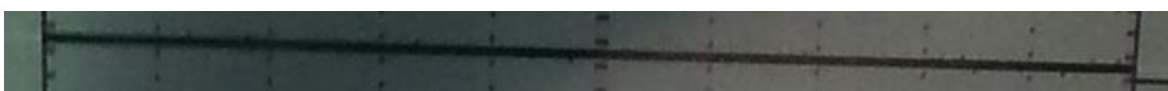


Figure 39 - Photodiode with 10uF capacitor

By interrupting the beam by hand at different rates the wave produced is shown below in figure 40.

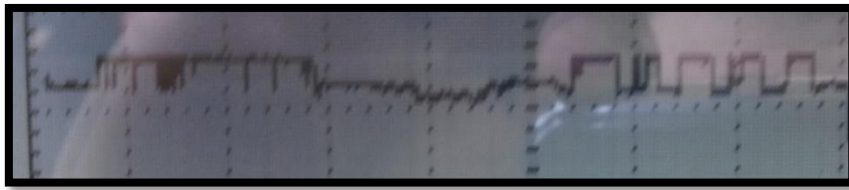


Figure 40 - Interrupting the beam by hand on the photodiode

Unfortunately the range is only between 420mV to 500mV and will need more work to improve the signal quality going to the Arduino before accurate results can be achieved. Additionally these signals provide rising edges and need to be inverted into falling edges before going into the signal measuring pin of the Arduino which will be explained in the next section. The way to invert the signal is to use a Schmitt trigger which can also clean up a noise signal. Some quick testing was setup to see how well it worked. Shown in figure 41 are the results of putting a push button through an inverting Schmitt trigger. Both the signal for the button and Schmitt trigger output is shown (channel 2 is the push button and channel 1 is the Schmitt trigger output). [66] Full testing circuit shown in appendix X.3.

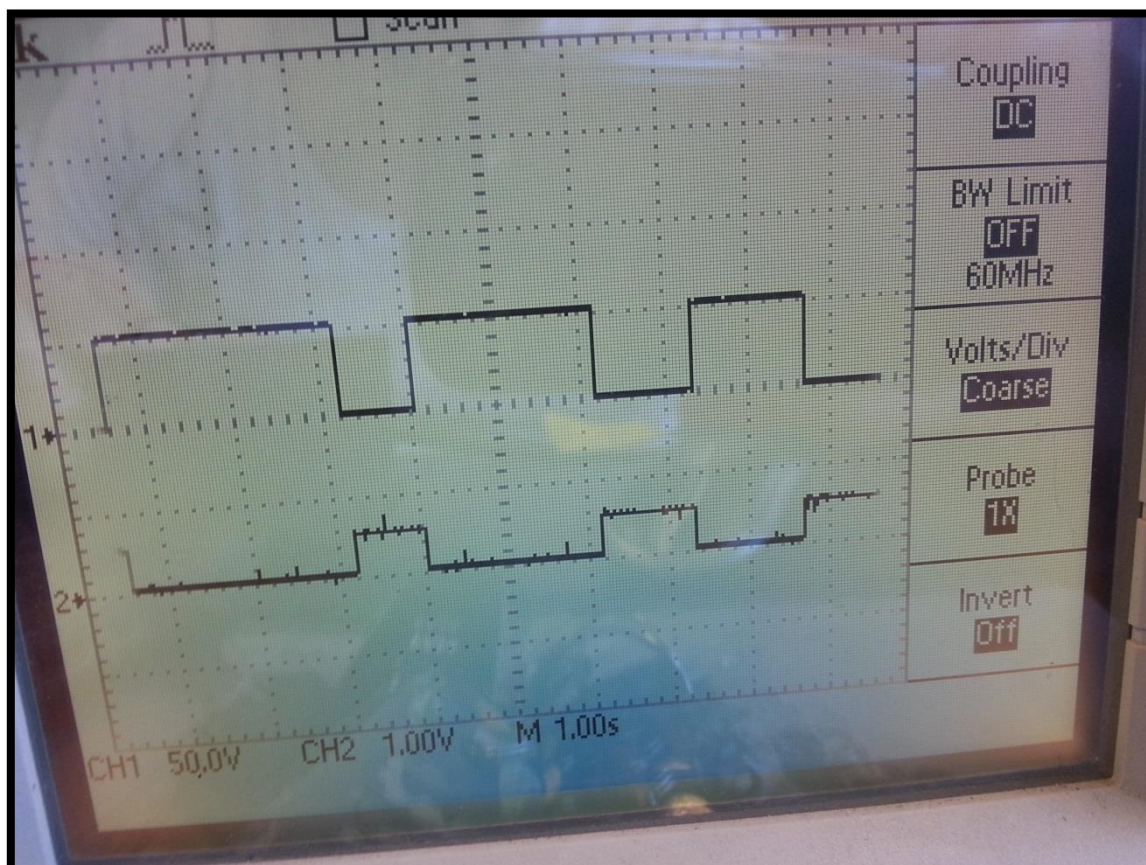


Figure 41 - Schmitt trigger behaviour

5.6 Final Programming

The final program touch ups include a password setup, an interrupt routine, internal pull up resistors activated and differing options in the final stage of a running program to go between displaying RPM to RADs.

The program on start-up will ask for a password to protect the device being used by anyone that can misuse the laser. To setup a password this thesis used the Password library created by Alexander Brevig (citation in library). The way it is programmed is that when a key is pressed on the keypad at the start of the program it shows what key was pressed and appends that key to a password. This is achieved by the code below:

```
password.append('1')
```

The code above, once executed, will store a “1” to the password by the function append when referred to the password library. To guess the password there is a function called “password.evaluate()” which will either produce a “true” or a “false” and can be used in an “if, else” statement. The program is designed to show “Incorrect password” if the password is wrong and “correct password” when the password is right. Moving onto the next part of the program.

For the Arduino to register a measurement to detect speed it is essential to use an interrupt service routine (ISR). Because the Arduino uses cooperative programming it cannot multitask unless it is given specific special commands. An “interrupt” as the name suggests will stop whatever the Arduino is currently doing and will give attention to the interrupt function. To setup an interrupt is shown in the code below:

```
attachInterrupt(0, counter, FALLING);  
pinMode(2, OUTPUT);  
digitalWrite(2, HIGH); [67]
```

Attaching an interrupt 0 of the Arduino Mega will mean that it will check pin 2 every clock cycle to see if an event has happened. Normally an input would be used but the second part of the pseudo code above sets up pin 2 as an output and line three sets pin 2 to “HIGH”. The reason for this is because it activates the internal pull-up resistor on the Arduino. So now a falling edge will register as a true for the Arduino when the signal comes through as such. This internal pull-up resistor will prevent a phenomenon known as “floating”. If pin 2 for example was setup as an input and it was waiting for a voltage to register a “high” sometimes false positives occur. So unless a pin was “pulled up” to a high voltage or “pulled down” to ground it is unknown what pin will read. [68] Full code shown in appendix X.4.

6 Results

Unfortunately the laser photodiode method was not implemented and will need a lot more work before being functional. However the Hall effect sensor works exceptionally well with clean edges for the Arduino to measure and calculate RPM and RADs. There are currently 4 options that can be chosen to display either RPM, RADs, the total count so far and the time between the last pulse.

The program begins with an initialization asking for a password shown in figure 42.



Figure 42 - Start up program

The program will proceed to compare the input password with the one stored in memory. It will display correct or incorrect password depending on the combination. And finally the third and final phase of the program will turn on the laser or Hall effect sensor and start counting. The different options are shown in figures 43-46.



Figure 43 - Displaying RPM and counts

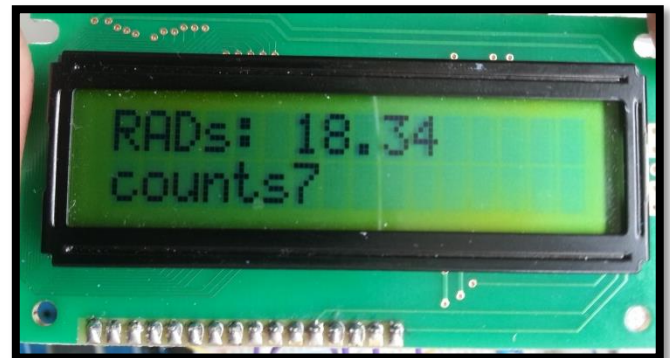


Figure 44 - Displaying RADs and counts

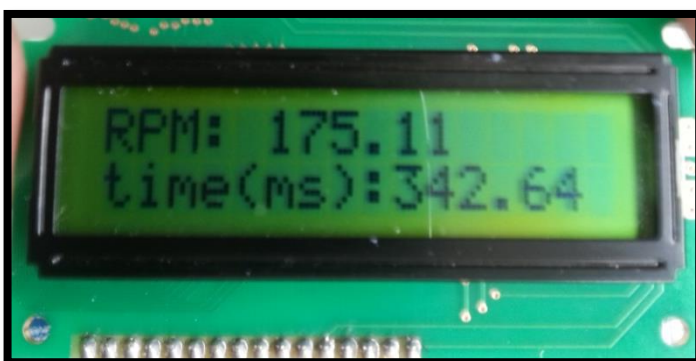


Figure 45 - Displaying RPM and period



Figure 46 - Displaying RADs and period

The power usage of the system was tested also with the total power drawn from the battery. This was done by putting a multimeter in series to measure current the battery just before hand was measured to be 12.7V. With just the power supply the multimeter read 5.11mA (figure 47) which is about 64mW. Once the Arduino was connected with the LCD the multimeter read 89.7mA (figure 48) which is about 1.14W. And finally when the laser was added the current rose to 282.9mA (figure 49) which is about 3.6W. Based on these results, with the battery able to produce 1.3 amp hours at 12 volts and if the current draw was a constant 300mA, then the battery would last 4.33 hours.



Figure 47 - Voltage regulator current draw



Figure 48 - Arduino, power supply and LCD current draw



Figure 49 - Arduino, LCD, power supply and laser current draw

7 Problems and Future Improvements

A few improvements need to be made to the laser and photodiode to make it operational. The problems are that the signal is quite weak at only 500mV peak and the range only spans between 420mV to 500mV which can be hard to work with. The first thing that needs to take place is an optical filter, since the laser is a green a clear green sheet of plastic or glass is all that is needed to filter out other wavelengths of light. This filter will only allow green light to pass. [69]. Once the rough filtering is completed a Sallen key active filter op amp circuit needs to be used. A high pass filter will eliminate the DC component or the offset from the ambient light and only allow those voltage surges that are created by the laser on the photodiode. Once the laser can register a signal on the photodiode then it will need to run through a Schmitt trigger to invert the signal so that the Arduino can detect a falling edge as a HIGH.

Another improvement which was originally taken into consideration is to include a “tone” library for the Arduino so that it can produce a sound. For example the faster it detects that the motor is spinning the higher in pitch and smaller in duration the sound. Also a maximum speed setting can be programmed on the programs start up that asks the user to input, and create an alarm sounds if it goes beyond a range either too slow or too fast.

Visual improvements can be made by adding a row of LEDs. This can be used to more visually display a maximum rotating speed like the speaker improvement suggestion.

At the moment the components are not contained inside a box. By providing a box for everything less damage will occur and even maybe shade some ambient light for the laser.

More components or sensors can be added as there is a large battery pack to support many

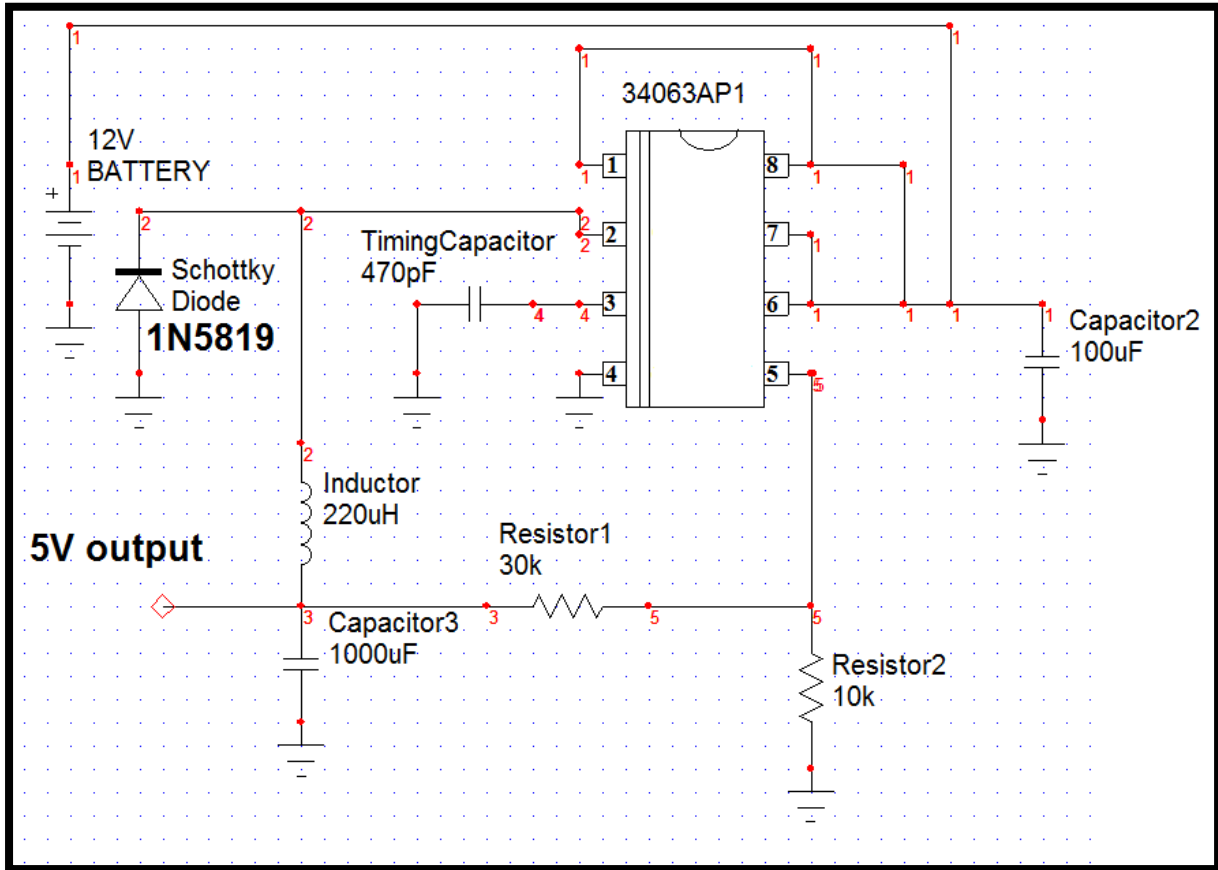
8 Conclusion

This thesis concludes that although the laser and photodiode didn't go as well as planned some more work could fix the issue but there is a lot involved. The Hall Effect sensor works perfectly and did so first time. The device created might be suitable for lower speed rotation but hasn't been tested on object with a higher angular velocity.

The objective was met: there is a working device that shows RPM and RADs with more switchable options for counts and period between revolutions. There is a password and keypad for extra safety with the activation of the laser so no one gets hurt. Many problems and damage could have been avoided, such as using more flexible wiring because rigid wire can easily damage sensitive electrical equipment.

X Appendix

X.1 Switching Power Supply



The circuit above was made using Intusoft ICAPS.

12 Volt input and 5 Volts output switching with an on off time. This on and off time is described by the datasheet as:

$$\frac{T_{on}}{T_{off}} = \frac{V_{out} + V_f}{V_{in} - V_{sat} - V_{out}} \quad T_{on} + T_{off} = \frac{1}{f}$$

Frequency derived from oscilloscope was 62500Hz if the estimated period was 16us from timing capacitor.

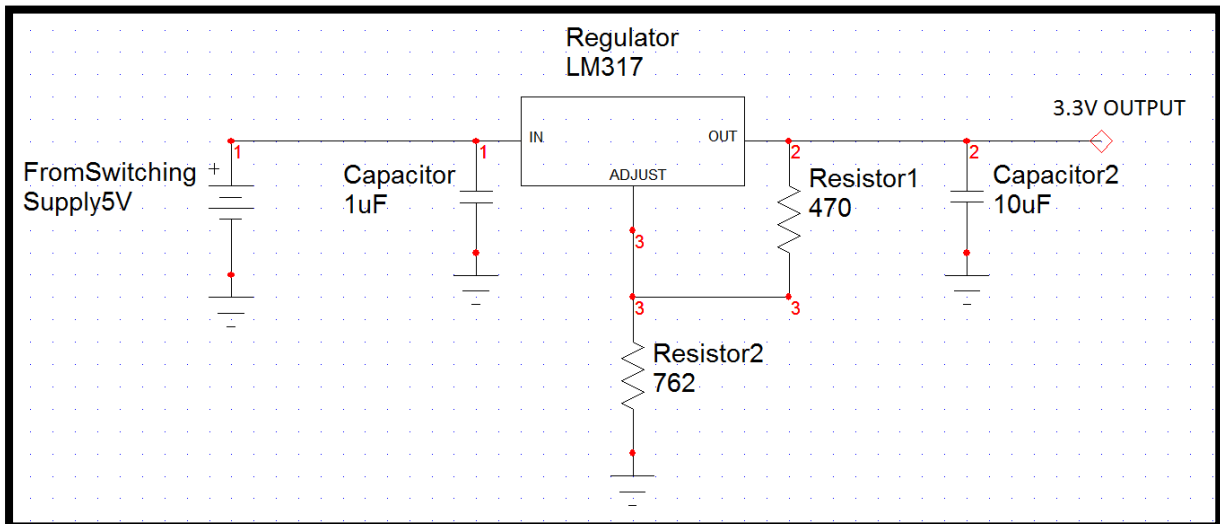
The voltage output is: (R2 = 30k and R1 = 10k)

$$V_{out} = 1.25 \left(1 + \frac{R2}{R1} \right)$$

Which is 5V as expected peak. The 1000uF capacitor is big enough to make the output appear as a DC voltage.

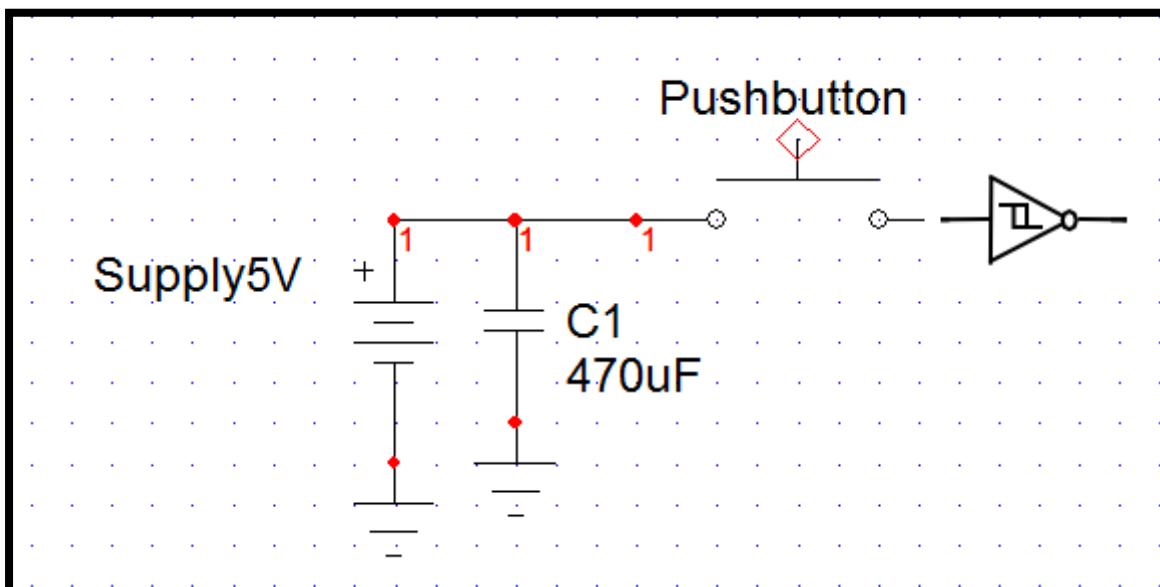
From link: <http://www.onsemi.com/pub/Collateral/MC34063A-D.PDF>

X.2 Linear Power Supply



The linear power supply is fed 5V from the switching power supply and then outputs 3.3V with the circuit shown above. Resistor 2 was a 1k variable resistor. The 2 capacitors are added for optional stability and are not needed.

X.3 Schmitt Trigger Circuit



Schmitt circuit used to test Schmitt trigger. The Schmitt trigger chip was model: MM74HC14N

X.4 Program used for Project

```

#include <LiquidCrystal.h>
#include <Keypad.h>
#include <Password.h>

int initialization = 1;
int preprogram = 0;
int program = 0;
volatile unsigned long count = 0;
int option = 1;
float RPM = 0;
float RAD = 0;
float elapsed = 0;
float start = 0;
float time = 0;
float Hz = 0;

Password password = Password("1337");

LiquidCrystal lcd( 50, 48, 46, 44, 42, 40, 38, 36, 34, 32, 30);

const byte rows = 4; //four rows
const byte cols = 3; //three columns

char keys[rows][cols] = {
  {'1','2','3'},
  {'4','5','6'},
  {'7','8','9'},
  {'S','0','H'}
};

byte rowPins[rows] = {4, 9, 8, 6}; //connect to the row pinouts of the keypad
byte colPins[cols] = {5, 3, 7}; //connect to the column pinouts of the keypad
Keypad keypad = Keypad( makeKeymap(keys), rowPins, colPins, rows, cols );

void setup() {

  lcd.begin(16, 2);
  pinMode(2, OUTPUT);
  digitalWrite(2, HIGH);
  attachInterrupt(0, counter, FALLING);
  lcd.clear();
  lcd.setCursor(0,0);
  keypad.addEventListener(keypadEvent);
}

void loop() {

```

```
char key = keypad.getKey(); //always running to get key
```

```
if (initialization == 1) {
    delay(2000);
    lcd.clear();
    lcd.setCursor(0,0); lcd.print("Enter Password"); lcd.setCursor(0,1); lcd.print("In ");
    delay(1000); lcd.print("5"); delay(1000); lcd.print("4"); delay(1000); lcd.print("3");
    delay(1000); lcd.print("2"); delay(1000); lcd.print("1"); delay(1000);
    password.reset();
    lcd.clear();
    lcd.print("Enter Password");
    lcd.setCursor(0,1);
    initialization = 0;
    preprogram = 1;
}
```

```
if (preprogram == 1) {
```

```
if (key)
```

```
{
```

```
switch (key) {
```

```
case '1': password.append('1'); lcd.print('1'); break;
```

```
case '2': password.append('2'); lcd.print('2'); break;
```

```
case '3': password.append('3'); lcd.print('3'); break;
```

```
case '4': password.append('4'); lcd.print('4'); break;
```

```
case '5': password.append('5'); lcd.print('5'); break;
```

```
case '6': password.append('6'); lcd.print('6'); break;
```

```
case '7': password.append('7'); lcd.print('7'); break;
```

```
case '8': password.append('8'); lcd.print('8'); break;
```

```
case '9': password.append('9'); lcd.print('9'); break;
```

```
case '0': password.append('0'); lcd.print('0'); break;
```

```
case 'S': lcd.clear(); lcd.setCursor(0,0); password.reset(); lcd.print("Enter Password");
```

```
lcd.setCursor(0,1); break;
```

```
case 'H': { if (password.evaluate())
```

```
{ lcd.clear(); lcd.setCursor(0,0); lcd.print("Correct"); lcd.setCursor(0,1); lcd.print("Password");
```

```
delay(2000); lcd.clear(); lcd.setCursor(0,0); password.reset(); preprogram = 0; program = 1; }
```

```
else
```

```
{ lcd.clear(); lcd.setCursor(0,0); lcd.print("Incorrect"); lcd.setCursor(0,1);
```

```
lcd.print("Password"); delay(2000); lcd.clear(); lcd.setCursor(0,0); password.reset();
```

```
lcd.print("Enter Password"); lcd.setCursor(0,1); }
```

```
break; } //end of H case
```

```
default : break;
```

```
} //end of switch case
```

```
} //end of switch case if statement
```

```
} //end of preprogram
```

```
if (program == 1) {
```

```

switch (option) {

case '1': lcd.clear(); lcd.setCursor(0,0); lcd.print("RPM: "); lcd.print(RPM); lcd.setCursor(0,1);
          lcd.print("counts:"); lcd.print(count); delay(100); break;
case '2': lcd.clear(); lcd.setCursor(0,0); lcd.print("RADs: "); lcd.print(RAD); lcd.setCursor(0,1);
          lcd.print("counts:"); lcd.print(count); delay(100); break;
case '3': lcd.clear(); lcd.setCursor(0,0); lcd.print("RPM: "); lcd.print(RPM); lcd.setCursor(0,1);
          lcd.print("time(ms):"); lcd.print(elapsed); delay(100); break;
case '4': lcd.clear(); lcd.setCursor(0,0); lcd.print("RADs: "); lcd.print(RAD); lcd.setCursor(0,1);
          lcd.print("time(ms):"); lcd.print(elapsed); delay(100); break;
default : lcd.clear(); lcd.setCursor(0,0); lcd.print("Choose"); lcd.setCursor(0,1); lcd.print("Option");
          delay(100); break;
        }
    } //end of program case
} //end of main void loop


void counter() {
    count = count++ ;
    elapsed = (micros() - start)/1000;
    start = micros();
    Hz = 1/(elapsed/1000);
    RPM = (Hz*60);
    RAD = (Hz*6.2831);
}


void keypadEvent(KeypadEvent key) {

    keypad.getState();
    if (PRESSED)
        option = key;
}

```

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